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TECHNIQUES FOR INJECTION LOADING OF
PBXC-303(1) EXPLOSIVE

C. D. Lind, et al

Naval Weapons Center
China Lake, California

October 1974

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(U) A study of the use of injection moldable explosives in detonation transfer mechanisms applicable to Trident I and/or Trident II was conducted. The study was aimed at providing design and processing data for developing these devices.

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Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. G. Freeman, III, RAdm., USN Commander
G. L. Hollingsworth Technical Director

FOREWORD

This report describes the study conducted by the Naval Weapons Center (NWC), China Lake, California, on injected explosive techniques. The work was accomplished by personnel of the Explosive Branch, Code 4541, during the period of July 1972 through December 1973. The effort was funded by Navy Task Assignment 77402, P.O. 3-0011/SSP013.

The material in this report has been reviewed for technical accuracy by Dr. Harold J. Gryting, Code 45401, NWC. The techniques reported herein are presented for use at the working level and are subject to modification.

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NOMENCLATURE

Symbol	Value	Meaning
A	poises	pre-exponential factor
E	cal	activation energy
L	cm	length
Q	cm ³ /sec	volumetric flow rate
R	cm	radius
S	dynes/cm ²	yield stress
T	°K	absolute temperature
n	--	flow index
t	sec	time
\bar{v}_z	cm/sec	average velocity
Γ	sec ⁻¹	$4Q/\pi R^3$
ΔP	dynes/cm ²	pressure
$\dot{\gamma}$	sec ⁻¹	shear rate
η	poises	non-Newtonian viscosity
μ	poises	Newtonian viscosity
τ	dynes/cm ²	shear stress

INTRODUCTION

With the Navy interim qualification of the injection moldable explosive PBXC-303(I) and its availability for development purposes, the utility of its characteristics in designing detonation transfer devices is being studied. (PBXC-303(I) is the designation for Plastic Bonded Explosive, China Lake -303 (Interim).) PBXC-303(I) is a puttylike material having the ability to flow into small cavities under low pressures. The detonation characteristics allow it to be used in very small diameter columns of 1 mm or less. The explosive, after injection, polymerizes to form an elastic rubberlike solid.

Major advantages of this kind of material are that it behaves as a non-Newtonian fluid during the filling or forming process and can be put into cavities of irregular shapes with varying diameters and closed ends. The use of plastic injection molding techniques can be applied to explosive device design.

The Naval Weapons Center (NWC), China Lake, California, has been studying injection moldable and extrudable explosives and their application to detonation transfer devices. Two items are currently under development at NWC for Fleet use. These studies are limited and generally apply only to the particular device being developed; however, some information can be applied to other systems. Several simple devices have been loaded and fired for specific applications. Injection rate determinations have been conducted.

There is a need to generate more information so that injection moldable explosives, which offer the potential of increased reliability and lower cost, can be applied to present and future defense and space-oriented systems.

HISTORICAL DEVELOPMENT

Explosives used in warheads and fuzes are processed by many different methods of which melt-cast, cold-slurry, pressed, or extruded dry powders are well known. Interest in improved explosive systems is a continuing pursuit at NWC. Such development encourages the search for new explosives, methods of handling, and their potential use.

Several years ago the Navy's interest in an explosive developed by the Atomic Energy Commission (AEC) for their particular purposes was centered about the specific booster explosive requirements for the Condor missile. However, as more weapons with greater sophistication and complexity were developed, the necessity of miniaturization and simplification of explosive fuzing, communication links, and explosive leads became more acute. As an aid in solving these problems of bulky and expensive explosive lines such as mild detonating fuzes (MDF), shielded mild detonating cords (SMDC), and confined detonating cords (CDC), and their attending interface problems, NWC prepared to investigate the AEC explosive, XTX 8003, which had been developed at the Los Alamos Scientific Laboratory. The prime purpose for XTX 8003 was for use in (1) initiation systems requiring simultaneous multipoint output of the explosive charge, and (2) explosive communication links from a single initiating detonator. This arrangement permitted a complete explosive integrated system.

Since open-channel explosive loading with XTX 8003 was already fairly well advanced, NWC decided to investigate other possible applications. The greatest potential use to Naval ordnance systems appeared to be in the filling of cavities and tubes, so procedures for injection molding of this explosive were initiated. In addition, details of manufacture of XTX 8003 were studied with the intent of relaxing the tight specification requirements for other than AEC applications and developing a similar explosive adaptable to broad conventional military use. NWC designated the new explosive as PBXC-303(1). The explosive has a puttylike consistency and cures to a resilient, flexible mass. Basically the explosive is 80% pentaerythritol tetranitrate (PETN) and 20% silicone resin (Sylgard 182).¹

The technique of injection molding involves the movement of explosive material into a cavity or tubing from a reservoir. This is accomplished by applying piston pressure to the explosive in the reservoir which forces the explosive into a cavity or tubing. When the accepting device is full of the explosive material, pressure on the piston is relaxed and flow stops. The device is then removed and set aside to allow the explosive to polymerize. The high solids loading of PETN provides for steady-state detonation in small cross-sectional channels or tubes.

¹Dow Corning Corporation, Midland, Michigan.

NOTE: Mention of commercial manufacturers in this report does in no way constitute endorsement of these sources or their products by NWC.

DESCRIPTION OF PBXC-303(I)

The Navy's PBXC-303(I) is an adaptation of AEC XTX 8003 with relaxed requirements of the PETN particle size distribution. Also, the mixing and handling requirements are less stringent than those required by the AEC. The two explosives are essentially identical in appearance, physical properties, and detonation velocity. It is believed by NWC that the relaxed requirements still provide a very adequate booster explosive for the Navy's conventional weapon needs. Table 1 lists a group of properties of PBXC-303(I). NWC has prepared a Purchase Description (PD) for Plastic Bonded Explosive, Injection Moldable PBXC-303(I), WS 12612. This PD document describes the chemical constituents, the rheological properties of uncured PBXC-303(I), and the methods of evaluating the explosive. A copy of the document can be procured upon written request to the Document Distribution Branch (Code 5554), NWC.

FINAL QUALIFICATION OF PBXC-303(I)

Several different AEC groups have qualified versions of PETN plus the Sylgard silicone resin. With this background and the added work that NWC had accomplished, NWC submitted a request for acceptance by the Navy as an interim qualified explosive. Final qualification will have taken place by the time this report is distributed. Upon service acceptance, this explosive (PBXC-303(I)) will be approved for use as booster/explosive transfer link material and thereafter designated as PBXN-301.

PROCESSING TECHNIQUES

PREPARATION

PBXC-303(I) is prepared by using two separate processing operations. The initial operation involves physically mixing the PETN and Sylgard resin ("premixing"); the second operation involves homogenizing or milling the premixed material. The Explosives Branch (Code 4541), NWC, has developed total "in-house" capability for the preparation, testing, and evaluation of PBXC-303(I).

PREMIXING METHODS

In order to minimize the potential hazard of handling dry PETN, NWC developed two premixing techniques for processing PETN with the Sylgard resin. The initial premixing technique used at N.W.C. was essentially the

TABLE 1. Properties of PBXC-303(I).

Composition, % by weight	PETN/Sylgard 182, 80/20
Melting point, °C, lowest melting constituent	140.0
Vacuum thermal stability (VTS) at 100°C, in ml/g/ 48 hr	0.12
Autoignition temperature, °C	179.0
DTA 1st exotherm, °C	160.0
Sensitivity, Type of test performed	Test result ^a
Impact 2-1/2 kg wt 50% pt cm	18.0
Friction ABL sliding pounds force	10/10 "No fire", 794
Electrostatic 50% pt joules	10/10 "No fire", 0.25
Small scale gap sensitivity 50% pt in decibangs (Bruceton analysis) @ 1.40 gm/cc	5.37 (cured)
Impact vulnerability 1/8-inch plate at velocity in ft/sec vs fires/ attempt	1,800-0/3, 1,950-3/12 2,100-9/9, 2,250-1/1

^aCured a minimum of 2 hours at 60°C.

same procedure as that being used for the preparation of XTX 8003 at the AEC facility at Burlington, Iowa. The AEC procedure required the use and handling of dry PETN during the premixing operation. A general description of the initial premixing operation conducted at NWC is as follows.

Alcohol/water-wet PETN was removed from the bulk storage container and dried in circulating-air steam ovens.² The dry PETN was weighed and transferred into a mixing bowl which contained the proper portions (10:1 by wt) of Sylgard 182 and curing agent (also from Dow Corning). These materials were then mixed remotely for a specified period of time at ambient temperature (65 to 80°F). At the end of the final mixing period, the premixed material, which had the consistency of slightly damp powder, was transferred to either a clean plastic container or directly into a roll mill for further processing. This method of premixing was considered to be acceptable; however, a less hazardous procedure that would minimize the handling of dry PETN was desired.

An alternate premixing method of preparing the explosive compound was later developed at NWC and is the one currently used. Alcohol/water-wet PETN is removed from the bulk storage container and placed into a Buchner funnel filtering assembly. Filtration by suction is applied until the liquid content has been decreased to not more than 10%. Isopropyl alcohol³ is added to the Buchner funnel containing the moist explosive (one part alcohol to three parts explosive by volume). Suction is again applied until the alcohol content is 10% or less. The alcohol washing is repeated three times. After final washing, the alcohol-wet PETN is removed from the Buchner funnel and put into a covered conductive rubber container. Moisture (alcohol) analyses are conducted using 10- to 20-gram samples as applicable. The adjusted weight of the alcohol-wet PETN is placed into the mixer bowl which contains proper portions of premixed Sylgard resin and curing agent. These materials are mixed remotely under vacuum (10cm Hg) for a specified period of time. At the end of the final mixing period (moisture analysis less than 0.05%) the "premixed" material is transferred either to a clean plastic bag or directly into the roller mill for further processing. The type of mixing equipment in current use at NWC is shown in Figures 1 and 2. Batches of up to 300 grams of premixed material can be prepared in the vertical Baker-Perkins 1-pint mixer.⁴ NWC has since installed a 1-gallon vertical Baker-Perkins mixer. It is anticipated that NWC will be able to prepare 4,500 to 6,000-gram premix batches using this mixer.

² Precision Scientific Co., Chicago, Illinois.

³ Isopropyl alcohol was found to be the best wetting liquid for the PETN. Ease of removal from premixed material and good desensitization of the PETN were the two prime factors determining the selection of isopropyl alcohol over several other commercially available liquids which were also investigated.

⁴ Baker-Perkins Inc., Saginaw, Michigan.

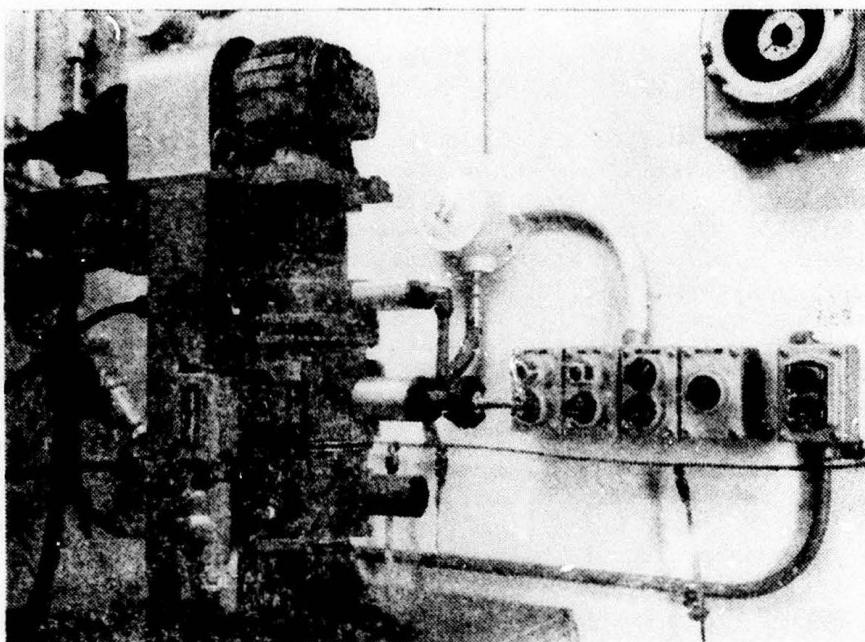


FIGURE 1. One-Pint Baker-Perkins Mixer.

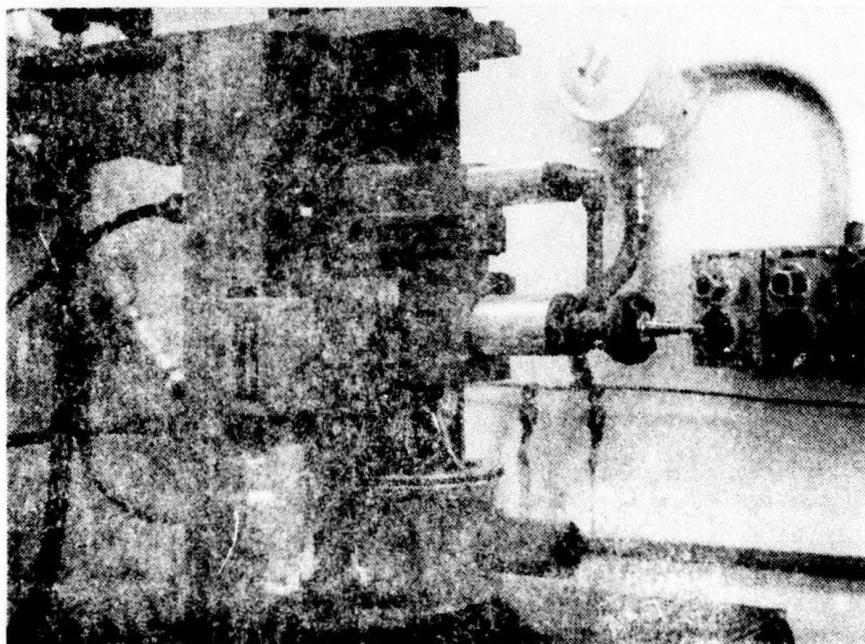


FIGURE 2. Mixer with Bowl Lowered Showing Mixing Blades.

MILLING OPERATION

The homogenizing or milling of the "premixed" material is a remotely controlled operation. A three-roller pigment dispersion mill equipped with a variable-speed drive, discharge apron, and a doctor blade is the type of equipment normally used for the milling operation. NWC has a three-roller laboratory mill⁵ modified for remote operation (Figure 3). The feed trough as shown has a batch capacity of 350 grams of premixed material; however, the setup can be altered to handle amounts up to 1,000 grams. The milling operation is also accomplished under ambient conditions.

Procedure

The roller speeds are adjusted to maintain a takeoff roller speed of 10.67 meters per minute (35 ft/min). A schematic diagram of the roller mill is presented in Figure 4.

A batch of premixed material is placed in the feed trough between the No. 1 and 2 rollers. The mill is started from the remote control station. The explosive material is passed through the mill, removed from the No. 3 roller by the doctor blade, and collected in a suitable container. A pass takes about 3 minutes. After each pass through the rollers, the mill is stopped and the material is manually transferred, using plastic gloves, from the collector back to the feed trough. Twenty-five consecutive mill passes are required for each batch of premixed material. The final product resembles glazier's putty in consistency. The milled batch is placed in clean conductive bags and stored. The shelf life of PBXC-303(I) at ambient temperature is approximately 24 hours. At -23 to -29°C (-10 to -20°F) the shelf life is increased to about 8 months. For this reason, refrigerated storage at -10°F or below is required.

TEST AND EVALUATION

The PD document (WS 12612) describes in detail the criteria to be used for the acceptance of a given batch of PBXC-303(I). This document lists all of the quality control and performance tests that are to be conducted on each production batch of PBXC-303(I). At the time that the PD document was prepared and approved, NWC did not have "in-house" capability for evaluating the explosive material in accordance with WS 12612 requirements. The primary reason for this lack of in-house capability was the nonavailability of AEC specified equipment necessary to perform certain of the tests.

⁵W. R. Frisch, Chicago, Illinois.

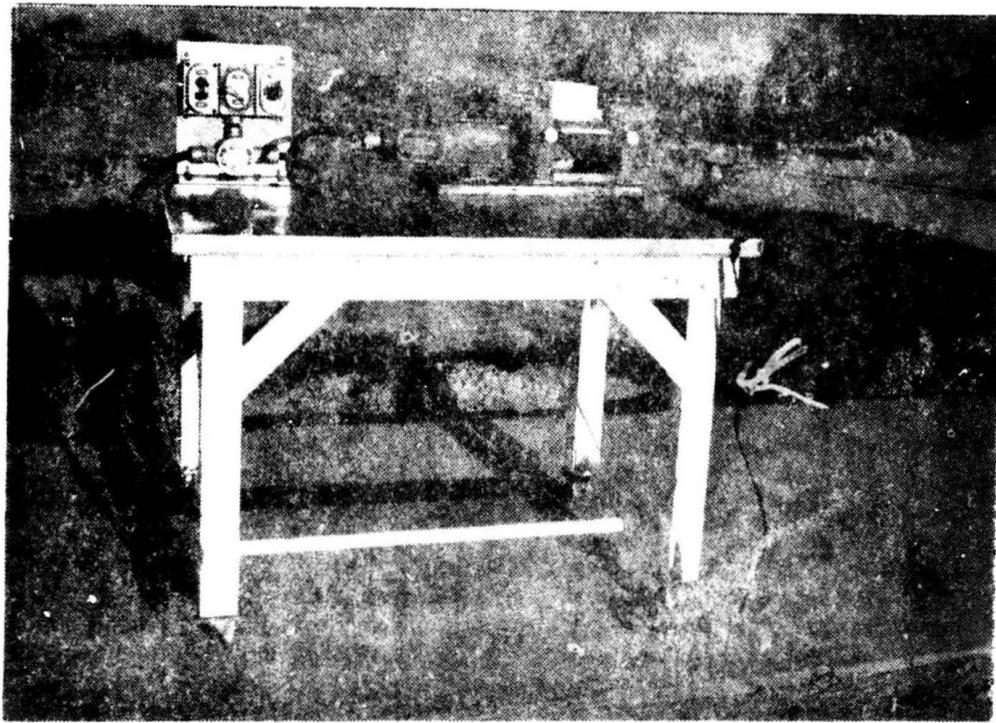


FIGURE 3. Three-Roller Laboratory Mill.

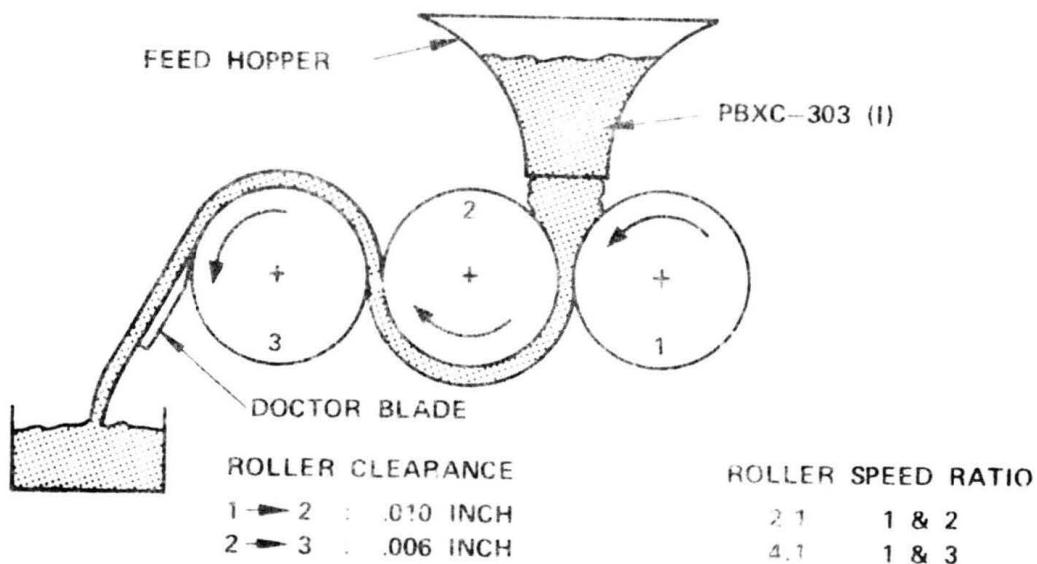


FIGURE 4. Schematic Diagram of Roller Mill operation.

In order to provide total in-house capability for evaluating PBXC-303(I), it was necessary for NWC to develop alternate test methods and procedures for: (1) an analytical method for performance composition analysis; (2) rheological measurements for quality control and for evaluating PBXC-303(I) for extrudability; (3) refinement of the method for determining propagation characteristics; and (4) a technique for making detonation velocity measurements in small channels.

The test methods and procedures needed to give NWC total in-house capability for quality control and performance evaluation of PBXC-303(I) have been developed and successfully checked out in the laboratories under this program, and are outlined in the following paragraphs.

RHEOLOGY

In general, flow problems can be formulated completely by using the equations of continuity, momentum, energy, and a rheological equation which relates the stress components to the rate of strain and previous strain history of the fluid. In addition, if the material is not incompressible an equation of state is required.

FLOW EQUATIONS

To simplify the equations, the isothermal flow of incompressible fluids subject to plane parallel shear will be treated. Isothermal conditions have been verified experimentally, that is, the fluid is not detectably heated by the low flow rates examined. The assumption of incompressibility seems reasonable since the density change caused by the applied pressure (up to 1×10^9 dynes/cm²) is small. The assumption of plane parallel shear is justified because of the large length to diameter (L/D) ratios investigated, and with high viscosities, turbulence is seldom encountered. With these assumptions, the rheological equation becomes:

$$\tau = \eta \dot{\gamma} \quad (1)$$

where:

τ is the shear stress

$\dot{\gamma}$ is the rate of shear

η is a coefficient in general dependent on the rate of shear of the fluid

If η is a constant, the fluid is Newtonian and $\eta = \mu$, the coefficient of viscosity. If η depends on the past shear history (i.e., is time dependent) the fluid is either thixotropic or rheoplectic. If a thixotropic fluid that has been at rest for a long period of time is sheared at a constant rate, its viscosity, η , will decrease with time; eventually reaching an equilibrium value corresponding to the particular state of shear. With rheoplectic fluids, η increases to eventually reach an equilibrium value.

Those fluids for which η depends only on the instantaneous state of shear are either pseudoplastic or dilatant. With pseudoplastic fluids, η decreases with increasing τ or $\dot{\gamma}$. With dilatant fluids, η increases with increasing τ or $\dot{\gamma}$. It has been found that plastics are usually pseudoplastic.

Various formulations of the functional relation between η and $\dot{\gamma}$ have been made. Two of the most useful ones describe power law fluids and Bingham plastics. For power law fluids:

$$\eta = \eta^0 \left| \frac{\dot{\gamma}}{\dot{\gamma}^0} \right|^{n-1} \quad (2)$$

where η^0 is the viscosity of the material at the arbitrarily chosen standard shear rate, $\dot{\gamma}^0$ (usually chosen equal to 1/sec).

The flow index for the fluid is shown as n . Note that for $n < 1$, the power law describes a pseudoplastic fluid, for $n = 1$ a Newtonian fluid, and $n > 1$ a dilatant fluid. Combining Eq. 1 and 2 gives the relationship between shear stress and shear rate for a power law fluid:

$$\tau = \eta^0 \left| \frac{\dot{\gamma}}{\dot{\gamma}^0} \right|^{n-1} \dot{\gamma} \quad (3)$$

If $\dot{\gamma}^0 = 1$, then the log of Eq. 3 is:

$$\ln \tau = \ln \eta^0 + n \log \dot{\gamma} \quad (4)$$

which shows that a plot of $\ln \tau$ versus $\ln \dot{\gamma}$, called the logarithmic flow curve, will be a straight line for those fluids which obey the power law.

The rheological equation of the Bingham plastic is derived under the assumption that the material is rigid below a certain yield stress and a power law fluid above the yield stress. Thus:

$$\left. \begin{array}{l} \dot{\gamma} = 0 \quad \tau < S_0 \\ \tau = S_0 = \eta^o \left| \frac{\dot{\gamma}}{\dot{\gamma}^o} \right|^{n-1} \quad \tau > S_0 \end{array} \right\} \quad (5)$$

where S_0 is the yield stress.

Since the viscosity of pseudoplastic power law fluids becomes large at low shear rates, it is difficult to experimentally distinguish between pseudoplastic power law fluids and Bingham plastics.

Using the rheological equation for a power law fluid (Eq. 3) and the conservation equations, the flow equations can be derived. The necessary assumptions are that the fluid does not "slip" at the wall of the tube and that the fluid viscosity is uniquely determined by its temperature and state of shear. Details of the derivations may be found in McKelvey.⁶ The results are:

<u>Factor</u>	<u>Formula</u>	
Shear stress at tube wall	$\tau_w = \left(\frac{R\Delta P}{2L} \right)$	(6)
Average velocity	$v_z = - \left(\frac{n\dot{\gamma}^o R}{3n + 1} \right) \left(\frac{R\Delta P}{2\eta^o \dot{\gamma}^o L} \right)^{1/n}$	(7)
Volumetric flow rate	$Q = - \left(\frac{n\pi R^3 \dot{\gamma}^o}{3n + 1} \right) \left(\frac{R\Delta P}{2\eta^o \dot{\gamma}^o L} \right)^{1/n}$	(8)
Shear rate at tube wall	$\dot{\gamma} = - \left(\frac{3n + 1}{n} \right) \frac{Q}{\pi R^3}$	(9)

where symbols not previously defined are:

R is the radius of the tube, L is the tube length, and ΔP is the applied pressure.

⁶ McKelvey, J. M. *Polymer Processing*. Wiley, New York, 1962. Pg. 65-69.

Combining Eq. 3 with 6 and 9 and taking the logarithm yields:

$$\ln \frac{R\Delta P}{2L} = \ln \eta^o + n \ln \frac{3n+1}{n} + n \ln \frac{Q}{\pi R^3} \quad (10)$$

This implies that plotting $\ln \frac{R\Delta P}{2L}$ versus $\ln \frac{Q}{\pi R^3}$ gives a straight line with slope equal to n and an intercept equal to $\ln \eta^o \frac{3n+1}{n}$. The usual practice is to plot $\ln \frac{4Q}{\pi R^3}$ instead of $\ln \frac{Q}{\pi R^3}$ which does not change the slope but the intercept becomes $\ln \eta^o \frac{12n+4}{n}$.

A more general derivation of the flow of the equations⁷ shows that there is a unique functional relationship between $\Gamma = \frac{4Q}{\pi R^3}$ and τ_w and the uniqueness of the relationship is independent of the nature of the fluid (except that the fluid must not "slip" at the walls). In other words, if Γ is plotted versus τ_w , a curve results that may not be a straight line, which shows the relationship of the measured variables Q , R , L , and ΔP and can be used to predict the results of further experiments.

The non-Newtonian viscosity, η , is a function of temperature as well as the state of shear. The conventional method of presenting data on the temperature dependence of η is with an Arrhenius equation:

$$\eta = Ae^{-E/RT} \quad (11)$$

where E is the activation energy at either constant $\dot{\gamma}$ or τ , R is the gas constant (in Eq. 11 only), T the absolute temperature, and A is a coefficient depending on the fluid. Equation 11 infers a plot of $\ln \eta$ versus $1/T$ is a straight line and this plot can be used to relate experiments at different temperatures.

Alves, G. E., D. F. Boucher, and R. L. Pinford. CHEM ENGR PROG, 48, 385 (1952).

In some of the expected applications of PBXC-303(I), the important question is the length of time required to load the material into a tube of given size with the material at a given pressure. The time to load, t , may be obtained by integrating Eq. 7 thus:

$$v_z = \left(\frac{n\dot{\gamma}^o R}{3n + 1} \right) \left(\frac{R\Delta P}{2\eta^o \dot{\gamma}^o L} \right)^{1/n} \quad (7)$$

If $\dot{\gamma}^o = \frac{1}{sec}$

$$v_z = \left(\frac{nR}{3n + 1} \right) \left(\frac{R\Delta P}{2\eta^o L} \right)^{1/n} = \frac{dL}{dt} \quad (12)$$

$$\int_0^t dt = \left(\frac{3n + 1}{nR} \right) \left(\frac{2\eta^o}{R\Delta P} \right)^{1/n} \int_0^L L^{1/n} dL \quad (13)$$

$$t = \frac{3n + 1}{(n+1)R} \left(\frac{2\eta^o}{R\Delta P} \right)^{1/n} L^{1/n+1} \quad (14)$$

Equation 14 gives the time-to-load a given tube as a function of the tube dimensions, the rheological constants for the material (n and η^o), and the applied pressure.

An alternate method, if the time-to-load one tube (t_0) of radius, R_0 , and length, L_0 , with a pressure, ΔP_0 , is known, is to use Eq. 15:

$$t = t_0 \left(\frac{L_1 R_2}{L_2 R_1} \right)^{1/n + 1} \left(\frac{\Delta P_2}{\Delta P_1} \right)^{1/n} \quad (15)$$

Equation 15 simplifies to Eq. 16 if $n = 1/2$:

$$t = t_0 \left(\frac{LR_0}{L_0 R} \right)^3 \left(\frac{\Delta P_0}{\Delta P} \right)^2 \quad (16)$$

RHEOLOGICAL PROPERTIES STUDY

To facilitate these studies of PBXC-303(I), an elementary capillary rheometer, locally called an "oozometer", was fabricated. The oozometer, shown in Figure 5, is simple in design and operation. A capillary tube with fixed L/D dimensions is hand-loaded with the test material and placed in position over the receiver cup in the structure provided. A vertically travelling loading device equipped with a piston of a diameter corresponding to the capillary tube is placed immediately above the capillary tube. The load tray is properly weighted and the piston is allowed to force the test material through the capillary tube into the holding cup. A dial gage gives the pressure exerted at the piston head and the time to evacuate the capillary tube is recorded by a stop watch. A portable cover with viewing window is placed over the oozometer while conducting the experiments.

The purpose of this study was actually two-fold: first, to provide a quality control test to determine the lot-to-lot and batch-to-batch variation of rheological properties of PBXC-303(I) and to determine how these properties change with storage age; and second, to provide a basis for predicting the "time-to-load" tubes of a given diameter and length. It will be seen that the first goal has been achieved. The second has yet to be attained.

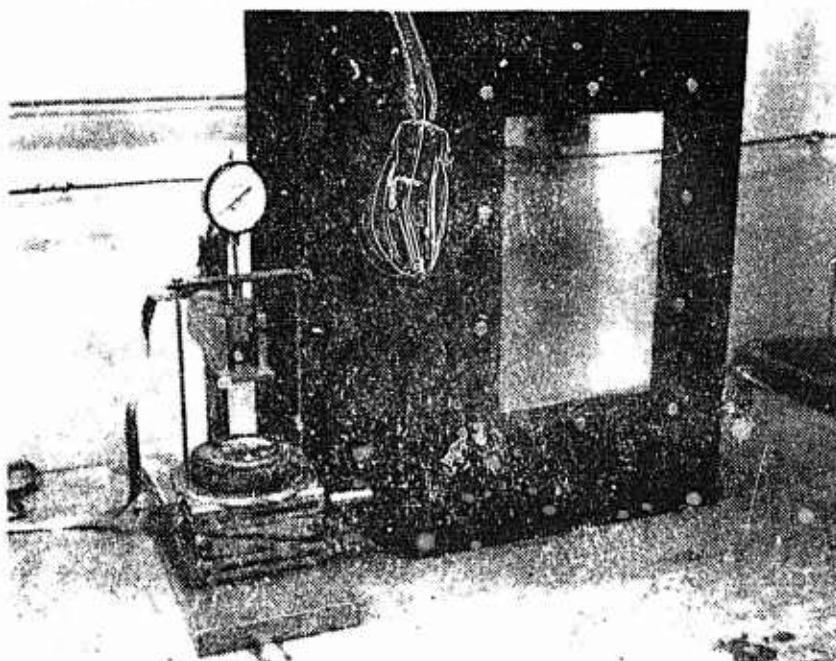


FIGURE 5. Simple Rheometer Called the "Oozometer" at NWC.

OOZOMETER RESULTS

Data from the oozometer are in terms of : (1) load, from which pressure (ΔP) can be calculated; and (2) piston travel and time, from which flow rate (Q) can be calculated along with the capillary constants (R and L). From these data, τ_w and Γ are calculated:

$$\tau_w = \frac{R\Delta P}{2L}, \text{ shear stress at the tube wall} \quad (6)$$

$$\Gamma = \frac{4Q}{\pi R^3}, \text{ measure of shear rate} \quad (17)$$

Any consistent system of units may be used. In this work, linear dimensions were in cm, Q in cm^3/sec , and ΔP in dynes/cm², thus τ_w is in dynes/cm² and Γ in sec⁻¹. If τ_w is plotted versus Γ on log-log paper, as in Figure 6, a straight line results indicating PBXC-303(I) is a power law fluid with a flow index, n , of 0.579. Since n is less than one, the material is pseudoplastic; that is, its viscosity decreases with increasing shear. Substituting the appropriate values in Eq. 6, 9, and 3 yields the rheological equation for PBXC-303(I):

$$\eta = 1.65 \times 10^{+5} \dot{\gamma}^{-0.421} \quad (18)$$

To determine if the viscosity of PBXC-303(I) is time-dependent (thixotropic or rheopectic), a sample that had been stored for several months was divided into two parts. The flow characteristics were determined with the oozometer on one part as received from storage. The second part was rolled on a roller mill and the flow characteristics immediately determined. The results were the same in both cases indicating the viscosity is either not time-dependent or the relaxation time (time to change back to the stable viscosity) is very short (< 10 minutes).

It is sometimes necessary, when analyzing capillary rheometer data, to make an entrance region correction. This is because, in the entrance to the capillary, fluid particles entering the tube from the reservoir are accelerated to their final steady flow velocities. The energy consumed in this process causes the pressure to drop more rapidly in this region than in the steady flow region. The error would be apparent when comparing data obtained with capillaries of different L/D ratios. The data of Figure 6 indicate no systematic difference between the data obtained with different capillaries even though the L/D ratios varied from 3.5 to 10. The analytical method of Bagley³ was used to determine

³ Bagley, E. B. J APPL PHYS, 28, 624 (1957).

the entrance corrections (which is a correction added to the actual length of the capillary) from the data and the correction was found to be negligible. It is possible that an entrance region correction is unnecessary for the oozometer because the capillary is constructed with a conical entrance section while most capillary rheometers have a square edge entrance.

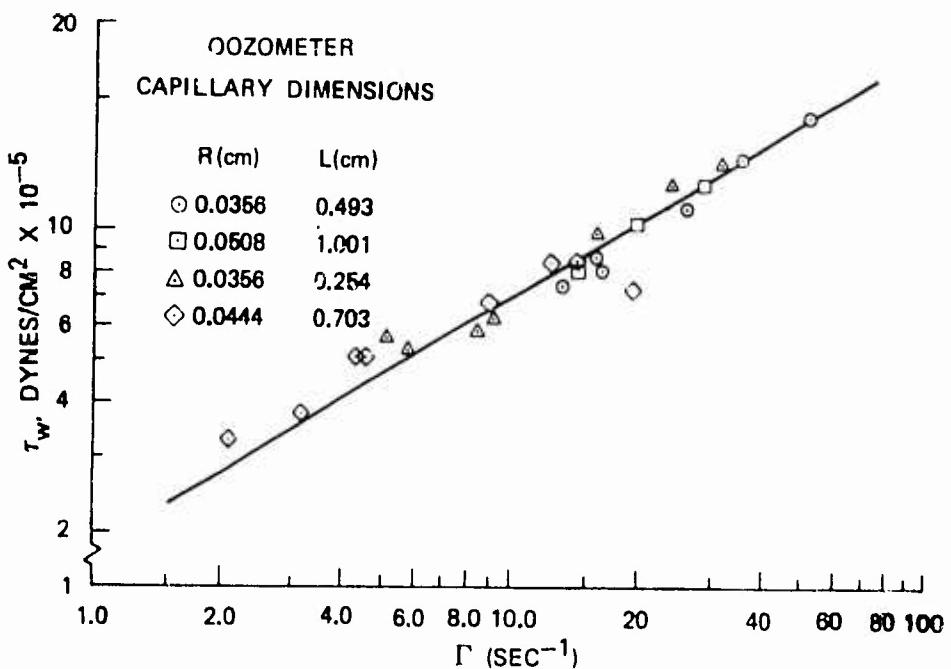


FIGURE 6. Logarithmic Flow Curve of PBXC-303(I).

While the temperature effect on viscosity of PBXC-303(I) was not studied extensively, several measurements were made at different temperatures. Only a limited temperature range (5 to 30°C) was investigated. The results are given in Figure 7 which shows the shear rate as a function of temperature at a constant shear stress of 9.8×10^5 dynes/cm². The curve indicates an approximately 2.5-fold increase in flow rate caused by a 25°C temperature rise.

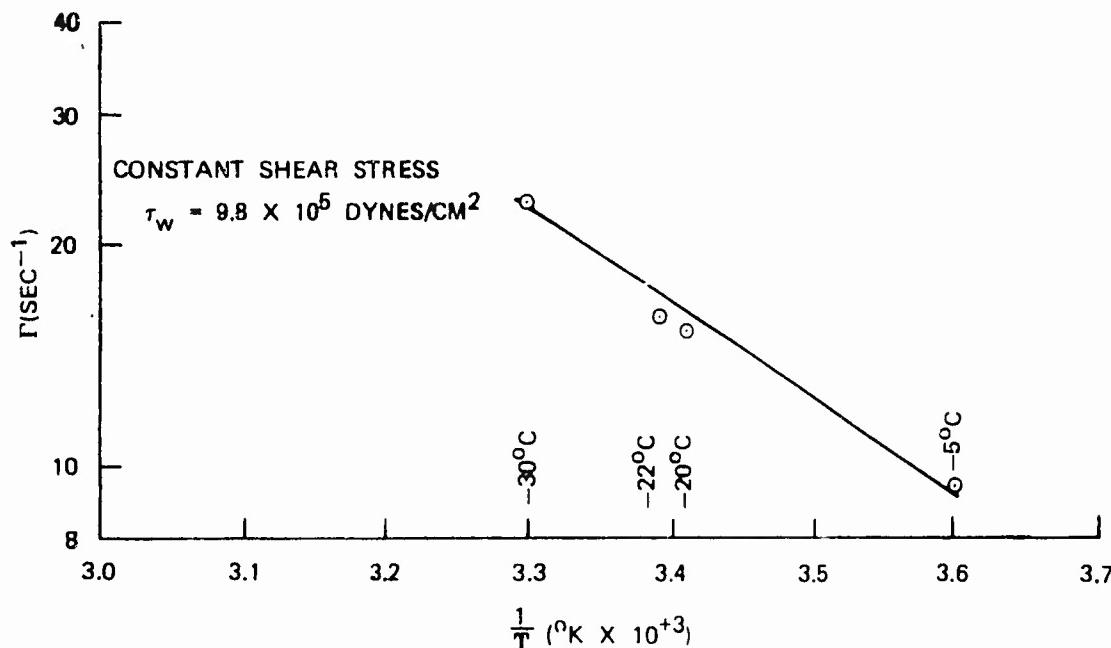


FIGURE 7. Temperature Dependence of Shear Rate.

LONG TUBE RESULTS

Stainless steel hypodermic tubing with inside diameters of 0.0508 and 0.104 cm was loaded with PBXC-303(I) in lengths of 50 to 213 cm. Stainless steel tubing was selected because of its ability to withstand high pressures, resistance to corrosion, and ready availability plus low cost. The rheological data were collected by two methods. Part of the tubing to be used was pretreated.

Tubing Pretreatment

The tube pretreatment lubrication consisted of (1) washing the tubes with detergent, (2) rinsing with distilled water, (3) drying with dry N_2 , and (4) lubricating with a 20% by weight solution of Sylgard resin in isopropanol. The tubes were again blown dry with nitrogen. Thus, a thin layer of the Sylgard liquid remained on the inside of the tubes. Much of the shear stress is taken up in this thin layer of liquid as the PBXC-303(I) is injection-loaded into the tube.

First Rheology Method

The long tubes were completely filled with explosive and the material was allowed to flow through for a given time into a container. The explosive was weighed and a flow rate calculated. These data are plotted in Figure 8 for 50-cm-long tubes and compared to oozometer data. These data would indicate that the shear stress within the longer tube is lower than that of the short (≈ 1 cm) oozometer tube. Temperature rise was at first thought to be the reason for this discrepancy; however, no temperature rise was detected when a tube was thermocoupled. During the writing of this report, it was found that minor exterior forces applied to the PBXC-303(I) column as it exits from the oozometer can cause discrepancies and variations in flow rates. These exterior forces may have been set up as the explosive column extruded itself into the collection cup of the oozometer, yielding a higher calculated shear stress.

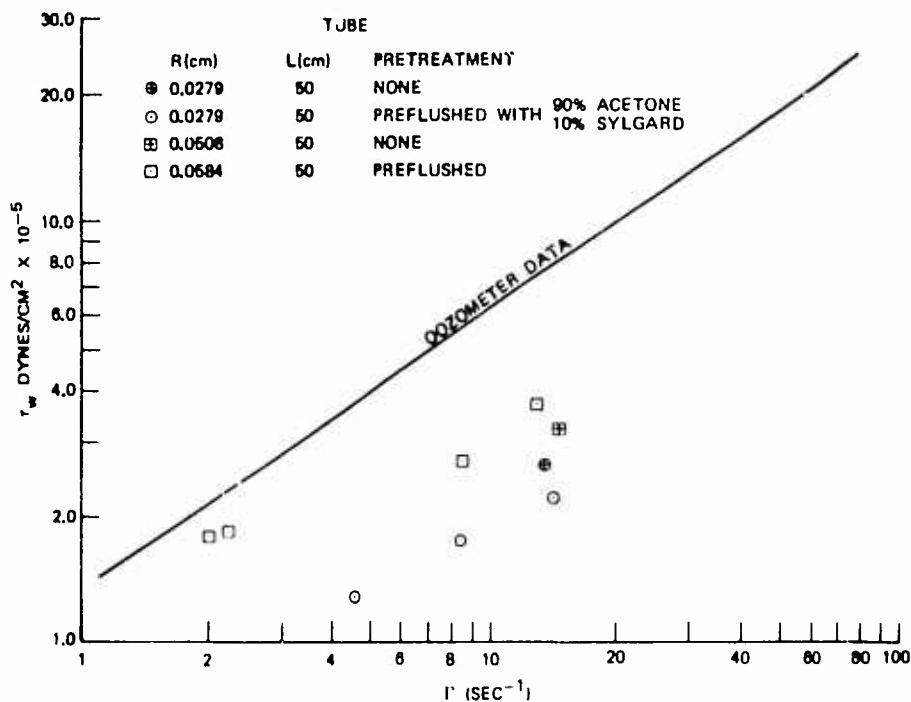


FIGURE 8. Logarithmic Flow Data of PBXC-303(I) in Long Tubes.

Exact correlation between oozometer and long tube data has not been achieved to date; however, approximate values of n and η^o can be obtained for preliminary calculations. Further efforts will refine oozometer operating procedures for more precise correlations.

Second Rheological Method

The "time-to-load" tubes of various lengths were used as the second data collection technique. These data are shown in Table 2 and plotted at $\ln t$ versus L/R (length to radius) in Figure 9. The slope is equal to $1/n + 1$. From the data $n = 0.51$, which correspond approximately to that of the oozometer data where $n = 0.579$, these data also yield $\eta^o = 1.19 \times 10^5$ poises at 1.38×10^9 dynes/cm 2 (20,000 psi) and 8.90×10^4 poises at 1.03×10^9 (15,000 psi) corresponding approximately to 1.65×10^5 poises from the oozometer. Note that the explosive was injected at 73°F. From Figure 8 it can be predicted that if the injection loading temperature is raised to 100°F, the flow rate should increase by about 1.5 times. Likewise, the time-to-load as a function of L/R can be drawn on Figure 9 for 100°F.

TABLE 2. Time-to-Load Tubes at Ambient Temperature (73°F).

Tube length, cm	Tube diameter, cm	Pressure, dynes/cm 2 $\times 10^9$	Time, seconds
91.3	0.104	1.38	307
91.3	0.104	1.03	190
121.8	0.104	1.38	681
121.8	0.104	1.03	617
152.3	0.104	1.38	1,349
152.3	0.104	1.03	1,322
182.7	0.104	1.38	2,655
182.7	0.104	1.03	2,922
213.2	0.104	1.38	2,525
91.3	0.0508	1.38	broke at weld
121.8	0.0508	1.03	6,000

Table 2 shows that at the two injection pressures there is very little difference in time-to-load; e.g., the same time-to-load can be achieved at 1.03×10^9 dynes/cm 2 (15,000 psi) as at 1.38×10^9 dynes/cm 2 (20,000 psi). One reasonable explanation for this result is that under higher loading pressures, and hence, high shear stresses, some of the liquid Sylgard lubricant is being scrubbed away from the tube wall rendering less lubricity. As discussed later in this report, a dry

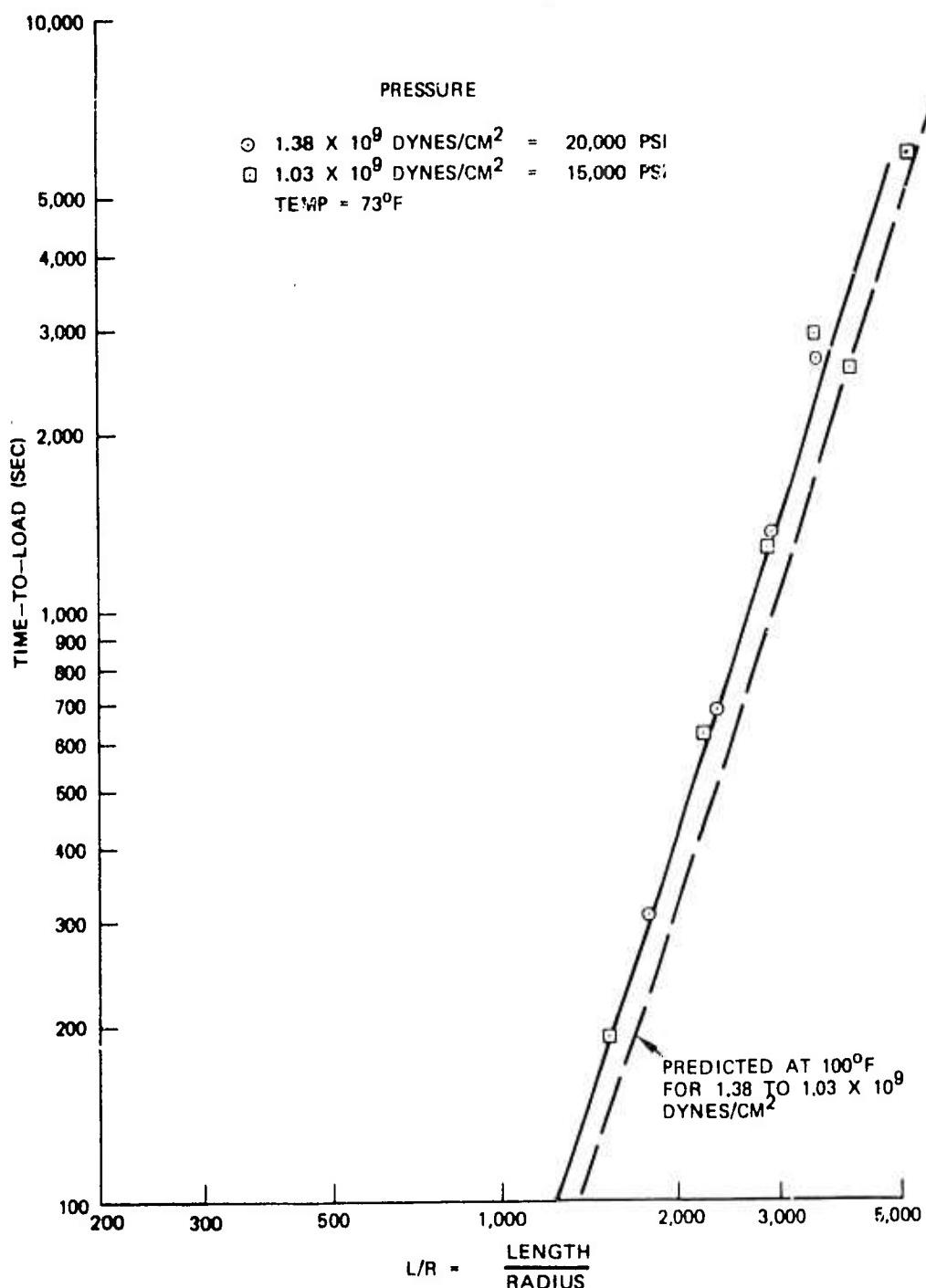


FIGURE 9. Time-to-Load Versus L/R Ratio.

lubricant which cannot be scrubbed off was tried; however, the time-to-load in 50-cm length tubes was not as short as with the wet lubricant technique; consequently, the wet lubricant was used for this set of experiments.

It is interesting to note that the 121.8-cm-long, 0.0508-cm-ID tube falls on the same line of Figure 9. With an L/R of 4,795, the time-to-load is 6,000 seconds. If this L/R relationship holds true, then it may be possible to make loading predictions for tubes of differing L/R when loading PBXC-303(I) at 1.03×10^9 dynes/cm² (15,000 psi). However, to verify this prediction it will be necessary to run additional tests.

METHODS OF IMPROVING INJECTION LOADING

When Lockheed⁹ specified their desire to have the capability of using small diameter, single element fuze lines of lengths up to 152.3 cm for the Trident missile system, NWC attempted to inject PBXC-303(I) in 0.104-cm ID thin-walled tubing. As reported in Table 2, the length of explosive injection time for a 152.3 cm section was about 1,300 seconds. The idea of diluting the Sylgard 182 resin with isopropanol alcohol was considered as a possible way to "wet" the tubing core surfaces. Since the Sylgard resin was used in the formulation of the PBXC-303(I), there are no problems of incompatibility. An 80:20 by wt mixture of isopropanol and Sylgard resin was established and this mixture was injected by a syringe into the long tubes to be loaded. The "coated" tubes were placed in a 140°F oven for several hours to ensure the absence of any of the alcohol. The resulting coated tubes did, in fact, improve the ability of the PBXC-303(I) to be injected into the tubes.

Tube Cleanliness

Following this partial improvement, it was decided to try to improve on the entire internal surface of the tubing, namely a systematic method of cleaning the tubing inner surfaces plus an investigation to find if there were other lubricating agents that might advance the injection flowability of PBXC-303(I).

⁹Lockheed Aircraft Corporation, Sunnyvale, Calif., USA

With regard to cleaning the tubing, inquiries were made of the tubing manufacturers as to their recommended cleaning technique. Since the tubing used is sold commercially for hypodermic needles, the cleansing techniques used in hospitals were adopted. The following cleaning procedure was resolved from the consensus of practical recommendations received:

- (1) Probe the length of tubing to be filled with a length of piano wire several mils smaller than the ID of the tubing. This procedure removed relatively large chunks of dirt, dust, and lint accumulated from tube storage and handling.
- (2) Flush the tubing with a soap and tap water solution. Use of a liquid detergent is recommended. A tablespoon of liquid detergent per gallon of water was used. This procedure removed the smaller dirt and dust particles which clung to the oily inner surface of the tubing. The soap and water solution was forced with a pressure of 20 psi through the tubing for 10 seconds. (All flushing was done at 20 psi pressure.)
- (3) Flush the tubing with clean tap water to remove the soap solution. This flushing was continued for 20 seconds.
- (4) Flush the tubing with acetone to remove any remaining surface layers of lubricating oil used in the drawing operation by the manufacturer. The acetone was flushed through each tube for 10 seconds.
- (5) Flush the tubing with water-pumped dry nitrogen for 10 seconds to insure the removal of any residual acetone (Figure 10).
- (6) Injection flush the prewetting isopropanol-Sylgard mixture. This coating procedure was injected at low pressure (20 psi) and a sufficient quantity forced through the tubing to insure that all surfaces were coated (Figure 11).
- (7) Oven-dry the coated tubing at 140°F for 2 hours to assure removal of the alcohol diluent.
- (8) Cover the ends of the tubing to prevent recontamination.

The tubing is now considered to be clean, coated, and ready for injection loading. The sealed tubing can be stored in virtually any position.

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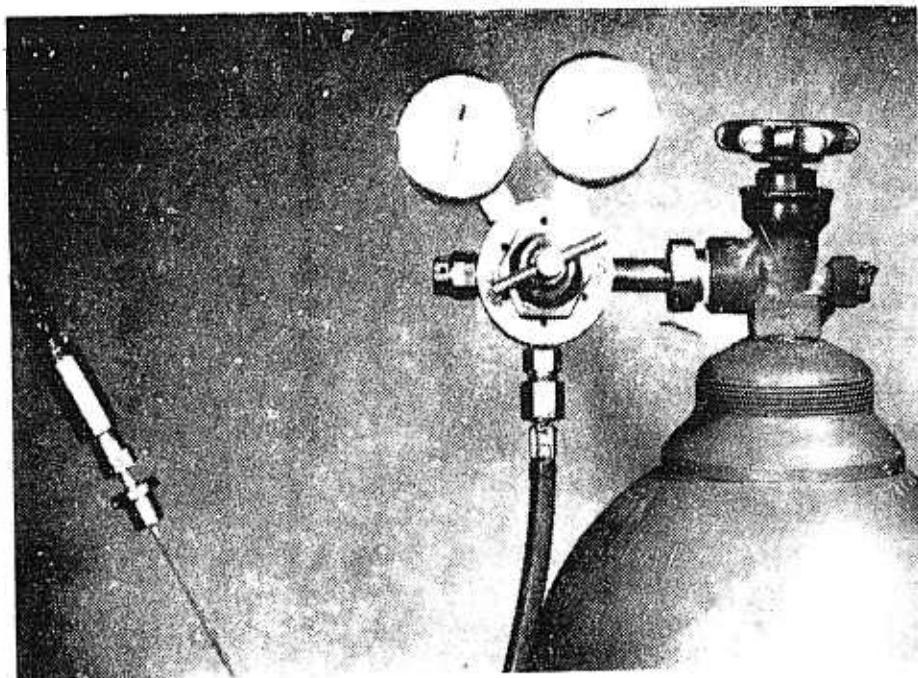


FIGURE 10. Equipment Used in Tube Cleaning.

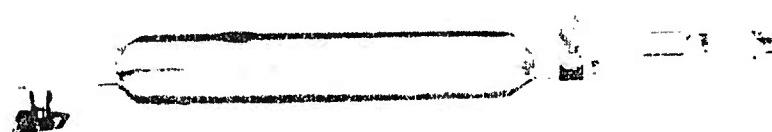


FIGURE 11. Equipment Used for Pressure-Coating the Tubing Cavity.

Prewetting Agents

Efforts were made to find additional prewetting agents. On a joint effort trip, an NWC chemist visited scientific personnel at Dow Corning. In addition, inquiry was made of the Explosives Branch, NWC, senior chemist who had had previous experience with fluorocarbon chemistry and the assessment of prewetting agents in attaching themselves to metal surfaces. This search culminated in a decision to try two recommended chemicals; Dupont TLF-1914¹⁰, a fluoralkyl phosphoric acid, and Tyzor AA¹⁰, an organic titanate primer.

Before attempting to injection-mold PBXC-303(I) into tubes coated with these chemical agents, it was necessary to run a complete compatibility study on the possible interaction that might take place between the chemical agents and PETN in particular. It was agreed that a differential thermal analysis (DTA), thermogravimetric analysis (TGA), and differential scanning calorimetric analysis (DSC) should provide the necessary data.

Thermal Compatibility Survey

DTA, TGA, AND DSC are techniques that provide a survey for thermal compatibility. DTA and TGA are simultaneously determined with the Mettler Thermoanalyzer-2 instrument.¹¹ This instrument records the difference in temperature between a sample and a reference substance as the temperature is raised linearly. TGA is obtained by mounting the sample and reference crucibles on a microbalance. Incompatibility of the components of a mixture is shown by the changes in temperature at which the sample reactions occur. The DSC device¹² measures the energy input to a sample and to a reference substance to maintain a constant heating rate. The instrument then measures the magnitude of the thermal effects, reaction, phase changes, etc., and the temperatures at which those reactions occur. Compatibility is indicated by the independent reactions of the components and/or lack of interaction between components.

The results of these compatibility studies showed that Tyzor AA in contact with PBXC-303(I) produced a rather violent exothermic reaction, while with the TLF-1914 and PBXC-303(I) there was no reaction. The results of these tests reduced the field of trial wetting agents to the Sylgard mixture and Dupont TLF-1914.

¹⁰ DuPont Co., Wilmington, Delaware.

¹¹ Mettler Instrument Co., Princeton, New Jersey.

¹² Perkin-Elmer Corp., Norwalk, California.

Prewetting Agents Evaluation

To evaluate the prewetting lubricating agents, three sets of two tubes each were used in conducting a test. Two tubes were cleaned, coated with Sylgard mixture, and properly cured; two others were cleaned, coated with TLF-1914, then cured. The final pair was simply cleaned and dried, the set aside as the control. All tubes were 50-cm long with internal diameter of 0.0584 cm. All six tubes were loaded under identical pressure conditions of 8.26×10^8 dynes/cm² (12,000 psi). The results of the test were:

<u>Tube Treatment</u>	<u>Time-to-Load, sec</u>
None	1,220
None	3,420
TLF-1914	1,200
TLF-1914	2,824
Sylgard	500
Sylgard	270

The reason for the sizable differences between identical tests of like tube treatments is not known.

DETONATION CHARACTERISTICS

VELOCITY MEASUREMENTS AND TECHNIQUES

Detonation velocity measurements were conducted on 50-cm-long stain-less steel tubes with PBXC-303(I). Average detonation velocity measurements of 7,200 meters per second were obtained in both 0.0508-cm and 0.104-cm tube ID. Wall thickness in both cases was approximately 0.025 cm. The tests were conducted to demonstrate that steady-state detonation is achieved in tubes of small inside diameters. The test arrangement was set up to provide no more than ± 10 meters per second error. With this basic system capability, however, time can be resolved in time interval measurements to 1 nanosecond and a 10-micrometer measurement in tube length can be provided. Resolutions of ± 1 meter per second are then possible. Due to the intricacy of the test setup, however, additional time and cost is required. For the purpose of these tests, which was to show that steady-state detonation occurs, the ± 10 meters per second should be adequate.

AIR GAP STUDIES

It is a known fact that swaged columns of explosive with diameters greater than those under consideration here have, at times, exhibited explosive powder separation due to rough handling or excessively tight bending. It remains, therefore, the opinion of those who use such devices that the problems of cracks or air bubbles in explosive communication links must be a serious consideration. For this reason, a series of tests was devised in an attempt to simulate cracks and air bubbles in PBXC-303(I) and to then determine the detonation characteristics across these induced air gaps of known size. It is accepted that unconfined column diameters of PBXC-303(I) will reliably propagate in sizes smaller than 0.025 cm. It is surmised that even should an air gap be created during the fabrication of an explosive column, the plastic flexibility of cured PBXC-303(I) would render complete diametric separation nearly impossible. It is a surety that a definite portion of the explosive cross-section would remain intact.

Air Gap Test Preparation

It became the purpose of these tests to evaluate the capability of PBXC-303(I) to initiate across air gaps in the explosive column contained in stainless steel hypodermic tubing. It should be noted that if care is exercised when placing the explosive in the tooling chamber, it is nearly impossible to create air bubbles in the explosive during injection loading into the tubing. This preventive condition is attained by pressing the explosive firmly in the loading chamber with clean plastic gloves thus precluding air entrapment in the corners of the chamber.

Evacuation of the loading chamber after assembly and prior to the pressing operation has been tried at NWC and was found to be of no particular advantage with the size of the tooling being used. It is a further consideration that due to the high injection pressures (up to 1.38×10^9 dynes/cm²) leakage past the O-ring seals would allow escapement of any unlikely entrapped air. The cross-linking of the binder agent during the cure period and the resultant flexible characteristics of the explosive would render nearly impossible the creation of cracks or air bubbles in the injection-molded column of PBXC-303(I).

Air Gap Tooling

To enable proper evaluation of FBXC-303(I) initiation capabilities, it was decided to fabricate tooling that would establish strict limitations on the air gap under test. The air gap was controlled by devising a spacer assembly. The device consisted of one round metal spacer with a center bore about as large as the core diameter of the explosive, and two metal washers with center bores equivalent to the outside diameter of the tubing containing the explosive core. The three components had

identical outside diameters. Alignment of the two adjacent explosive cores as well as the interspace was of great concern. Thus to assure proper axial alignment of the two explosive cores, a set of alignment tooling such as shown in Figure 12 was fabricated. The alignment instrument consisted of a male and female fitment pin and tube arrangement, attached to metal grasping blocks, permitting the assembly of the two washers and the centered spacer in such a way as to assure centering and alignment of the ends of the explosive columns. The washers and spacer were cemented together with Loctite CVV.¹³ One set of hardware and one spacer assembly were fabricated initially.

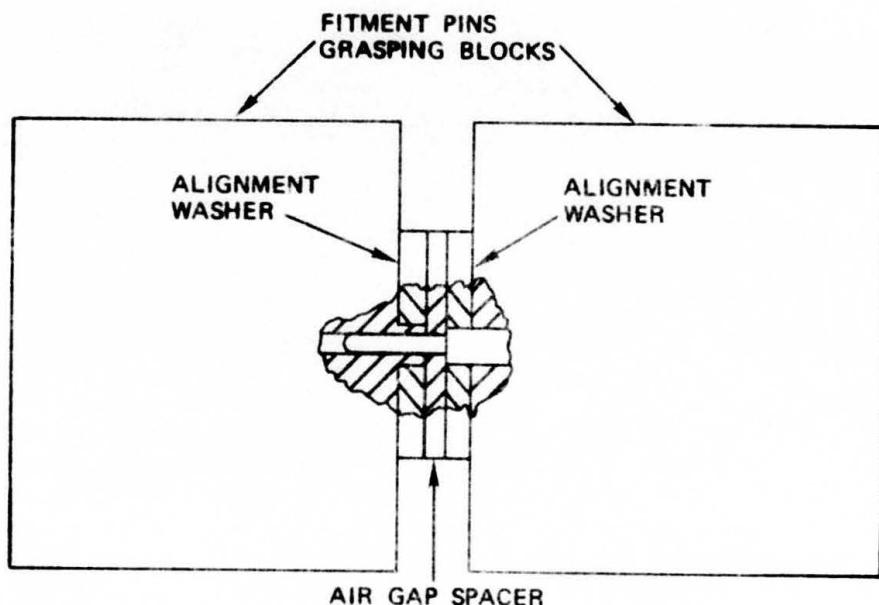


FIGURE 12. Core Alignment Tooling.

First Air Gap Test Series

The air gap tests were conducted in two series. It was intended to load tubing with inside diameters (and thus explosive cores) of 0.0508 and 0.091 cm. It was hoped that the explosive might detonate across a gap equal to its core diameter. The early plans for initiation

¹³Loctite Corporation, Newington, Connecticut.

verification included air gap tests of 0.126 to 0.761 mm in 0.126-mm increments. Explosive columns were made as shown in Figure 13. Twelve such assemblies were made up, each with a length of 5 cm. Six test assemblies were 0.0508-cm ID and six were 0.091-cm ID.

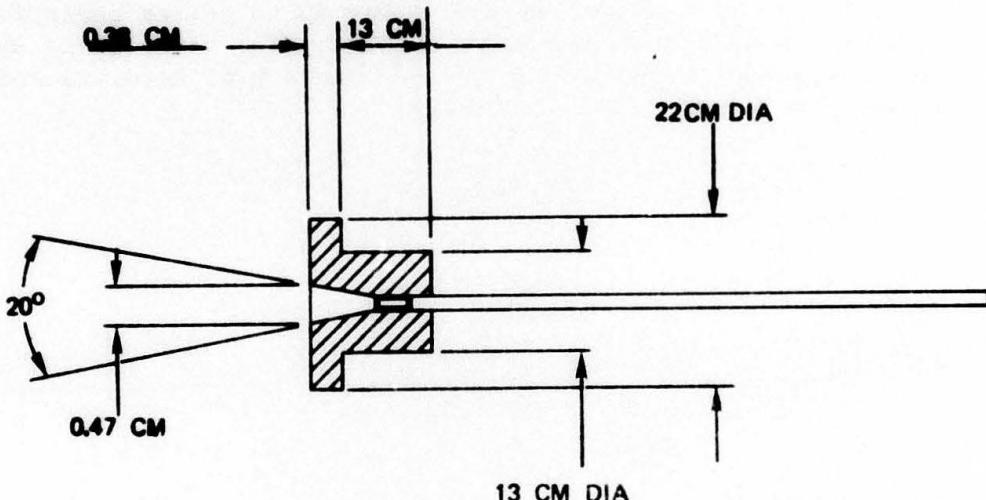


FIGURE 13. Acceptor End of Typical Explosive Column.

Since the induced air gap of 0.126 mm appeared to have the greatest likelihood of success, it was initially tested using the first set of air gap tooling previously described. The first pair of 0.0508-cm explosive tubes was assembled together for testing. The open ends of the tubes were inserted through the two sides of a plastic U-shaped holder and connected together using the air gap spacer device (Figure 14). Initiation of the donor explosive column was accomplished by attaching an exploding bridgewire detonator (designated RP-80)¹⁴ to the acceptor end of the test unit. This test was repeated with the second 0.0508-cm ID explosive tube. Both tests resulted in failure to transfer. A failure is evidenced by the witness plate and any residual receptor tubing (Figure 15). It was then decided to eliminate the air gap and attempt to butt the ends of the two loaded tubes together. This forms a relatively loose interface with a finite, but not easily measured, air gap. The test setup is illustrated in Figure 16. Two tests were made, each with successful propagation.

¹⁴ Reynolds Industries, Los Angeles, California.

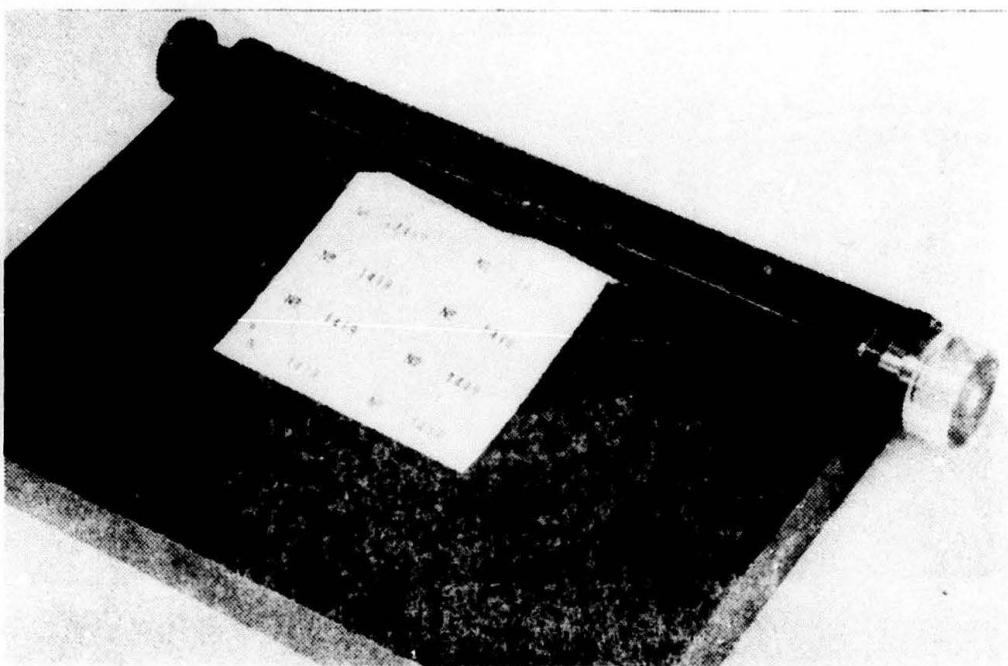


FIGURE 14. Overall View of First Air Gap Test Setup.

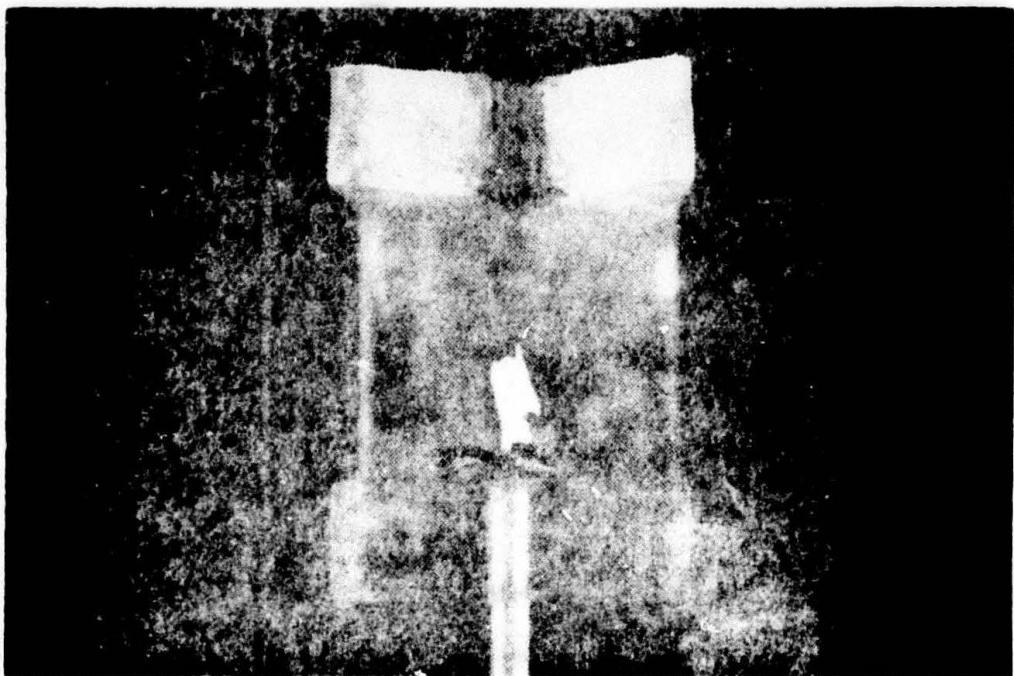


FIGURE 15. Close-Up View of Transfer Failure.

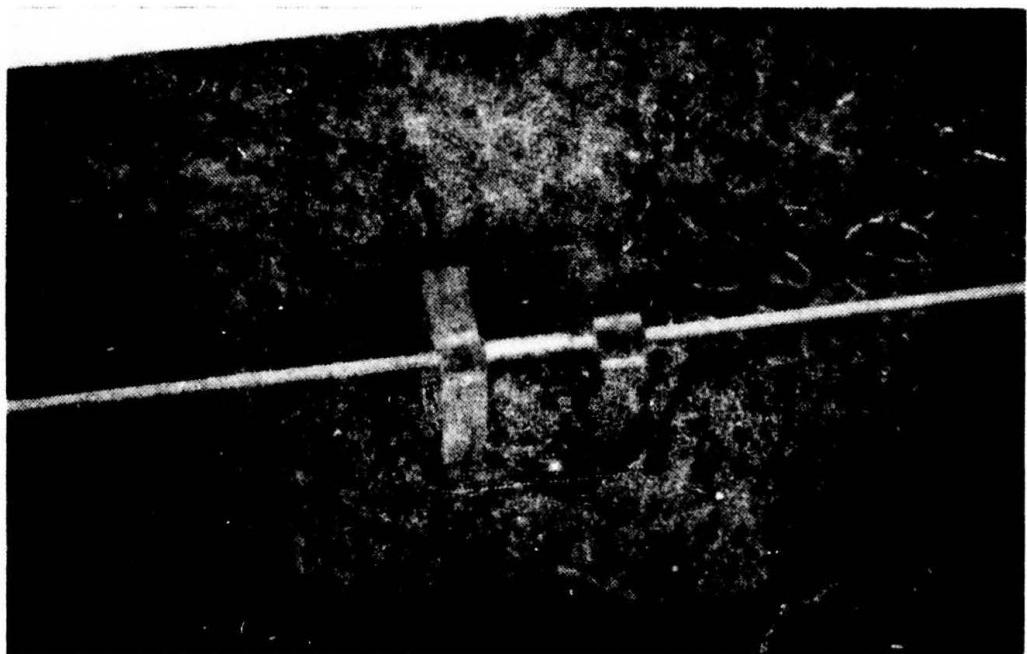


FIGURE 16. Setup for First Explosive Column
Abutment Air Gap Test.

Second Air Gap Test Series

Since the results of the first series of gap study tests proved that propagation across gaps smaller than 0.126 mm must be considered for small core loaded tubing of the size 0.0508 cm diameter, it was then reasoned that the detonation transfer across air gaps of larger core diameters should also be considered. A minimum number of test samples were again prepared in stainless steel tubing with core diameters of 0.0508, 0.104, 0.137, and 0.157 cm. For induced gap size, 0.076 mm was established. The reasoning for the selection of a 0.076 mm gap is based upon the experimental knowledge that a 0.076 mm gap can be seen on an N-ray (Neutron) exposure.

The gap introduced during the first in this series of tests was carefully established by removing the explosive from the open ends of the tubing. The open ends of the 0.0508 cm cores were then butted together in a bracket with tie-down sensors. The surface ends of the tubing had been hand-honed to provide for squareness of the mating ends; the resultant gap was 0.10 ± 0.02 mm. The test setup for the 0.0508-cm ID tubing is shown in Figure 17. The detonation shock wave across the 0.10 ± 0.02 -mm air gap successfully initiated the acceptor tube explosive core.

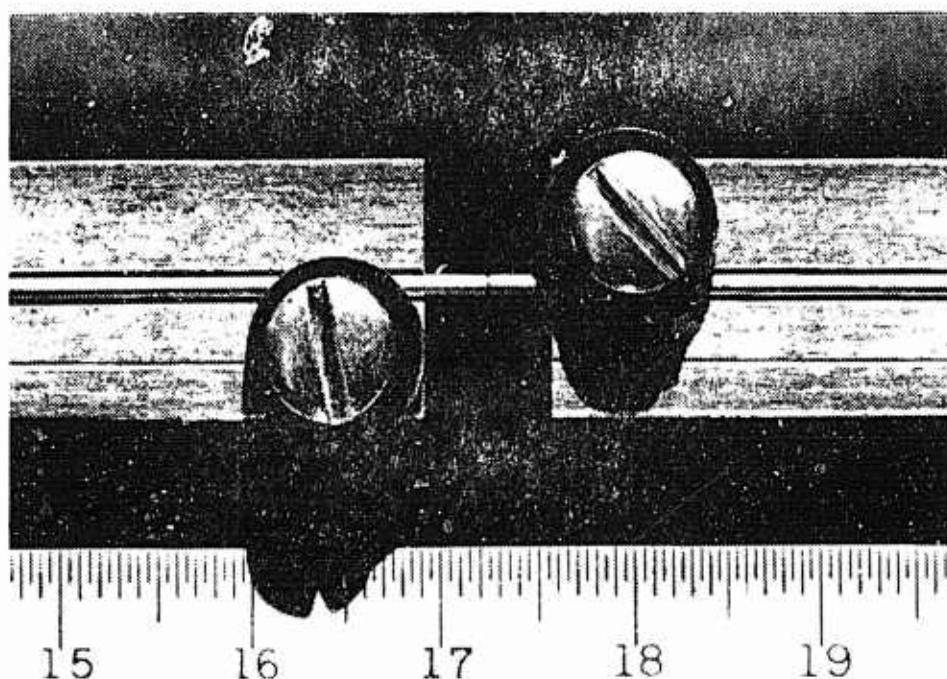


FIGURE 17. Close-Up of Abutted Tube Ends
for Air Gap Test (Scale Marked in cm).

The remaining tests of the 0.104, 0.137, and 0.157-cm ID tubes were conducted using 0.10-mm air gap spacer assemblies (described under *Air Gap Tooling*). Typical test setups are shown in Figures 18 and 19. These tests were all successful.

Figures 20 and 21 are photographic copies of N-ray inspections of the stainless steel tubes with inside diameters of 0.0508 cm and a wall thickness of 0.16 mm. These examinations were performed to determine how visible cracks, air bubbles, and separation of the explosive from wall surfaces might be. Figure 20 shows the profile of the explosive in the tube. The quality of the original N-ray film was excellent; however, the reproduction of the N-ray is not as good as desired, but the 10X enlargement does show the tubes' steel wall and the profile of the explosive within the tube. It will be noted in Figure 21 that the profile end of the explosive core has been disturbed. During the injection molding operation, a piano wire was probed into the open end of the tubing to determine the length of explosive fill. In this case, on withdrawing the wire, a small portion of uncured PBXC-303(I) stuck to the wire momentarily and produced an induced gap in the explosive column. The exhibited gap is about 0.25-mm wide and clearly visible to the naked eye when observing the normal size of the partially-filled tube image on the N-ray negative. It is estimated that if the image picture (continuous exposure along a loaded tube), could be enlarged 10 times, that at least a 0.076-mm gap, crack, or explosive separation would be visible.

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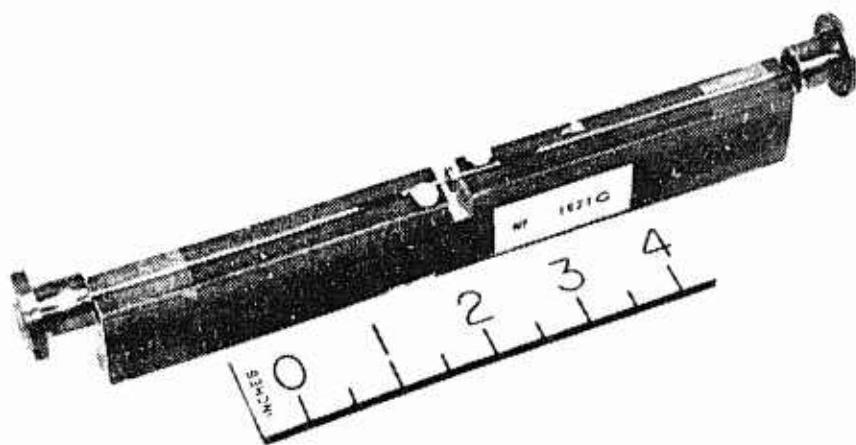


FIGURE 18. Typical Setup for Propagation Testing.

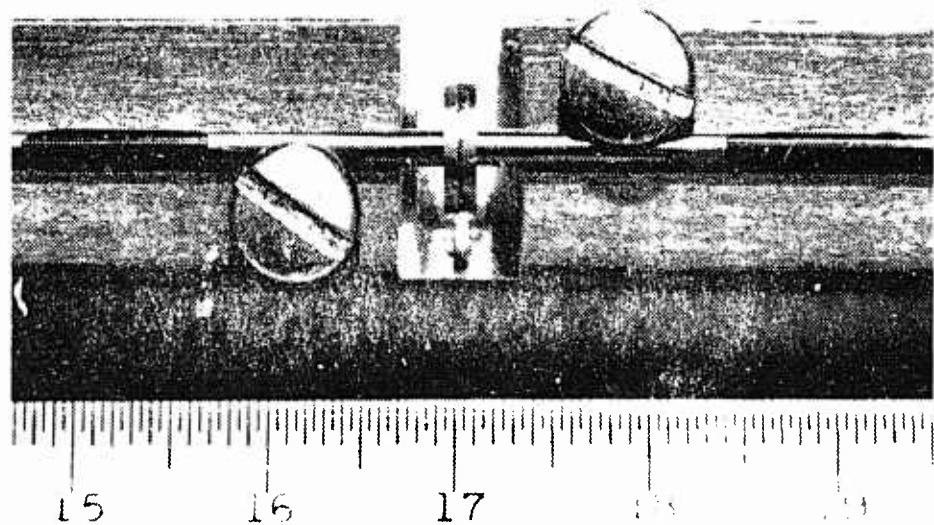


FIGURE 19. Close-Up of Typical Test Setup Using Air Gap Spacer (Scale Marked in cm).

NWC TP 5615

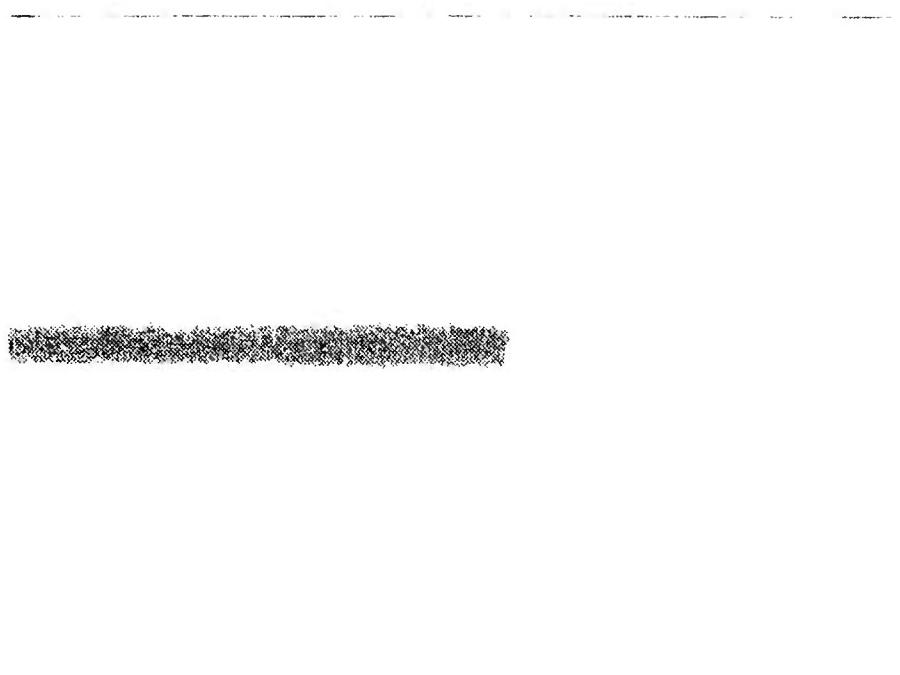


FIGURE 20. N-Ray Reproduction Showing Explosive Profile.



FIGURE 21. N-ray Reproduction Showing Disturbed Condition of Explosive.

APPLICATION

UTILITY FOR WEAPON SYSTEMS

The Phoenix missile was the first weapon system for which PBXC-303(I) was considered by the Navy as a possible booster explosive. Secondly, PBXC-303(I) was proposed for use in the Zuni explosive warhead in which the axial initiation SMDC explosive cord, leading from the nose fuze to the base initiation booster, was proposed to be replaced by a single element continuous column of PBXC-303(I). The PBXC-303(I) was injection molded into a length of aluminum tubing, equipped with receptor and donor ends (see Figure 22). The method of loading provided for no interfaces of explosive surfaces. The device consisted of a cone-shaped acceptor area and an enlarged output section. The entire lead is one complete integrated unit containing a continuous column of PBXC-303(I). Approximately 200 of these units have been successfully tested in accordance with the requirements of MIL-STD-810B.

PBX-303(I) is used or contemplated for use in the following Naval weapon systems or concepts as a booster explosive or communication link: Condor, Sidewinder, FAE, Zuni, Experimental Land Mine, and Explosive Logic Elements.

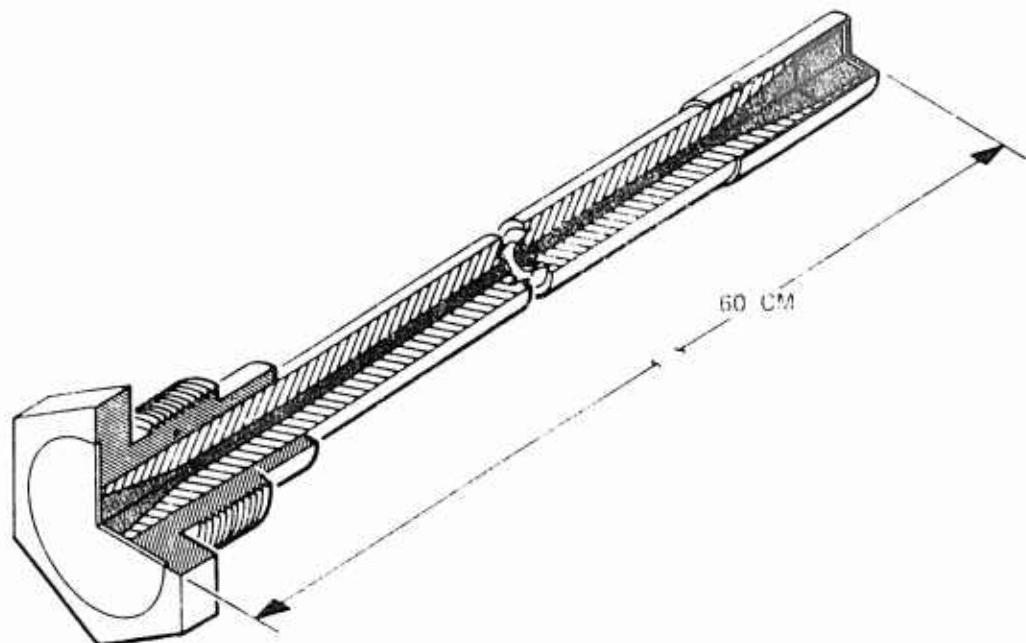


FIGURE 22. Continuous Explosive Column for use With Zuni Weapon.

TOOLING FOR INJECTION LOADING

The injection loading tooling is considered to be experimental in design but it does provide for adaptation to loading short or long tubes, both heavy wall as well as hypodermic tubing. The tooling is also adaptable for loading plates containing open channels. The experimental loading tooling is shown in Figure 23 and schematically in Figure 24. The nominal force on the ram ranges from 8,000 to 20,000 pounds. Tubes up to 304-cm long can be loaded using the same equipment with slight modification, as shown on Figure 25.

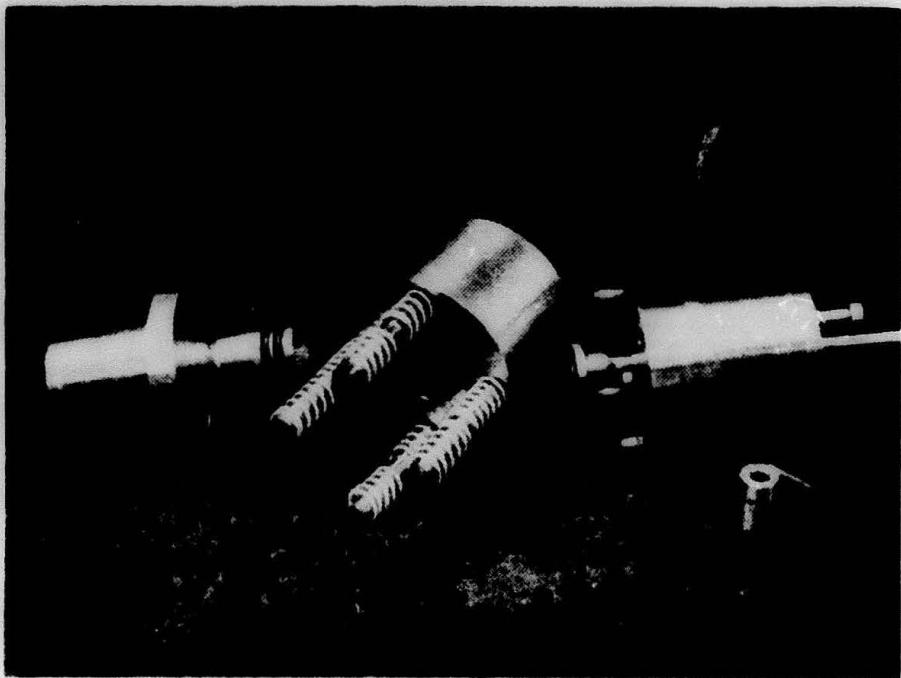


FIGURE 23. Injection Loading Tooling.

Early in this development program, consideration was given to loading plastic and rubber tubing of the size 0.063-cm OD with core hole sizes of 0.076, 0.100, 0.120, and 0.150 cm. To load these tubes it was necessary to confine the tube or tubes in a metal cylinder machined to take several plastic or rubber tubes. This tooling is illustrated in Figure 26. This procedure is practical for "gang-loading" operations from a single injection molding press. The length of tubing loaded for the experimental tests was 7.59 cm. The length of plastic or rubber tubing that can probably be loaded in this manner is dependent on tool design and good sealing practices. It is realistically anticipated that lengths approaching 152 cm can be gang-loaded in this manner with adequate tooling design and a press capable of high pressures.

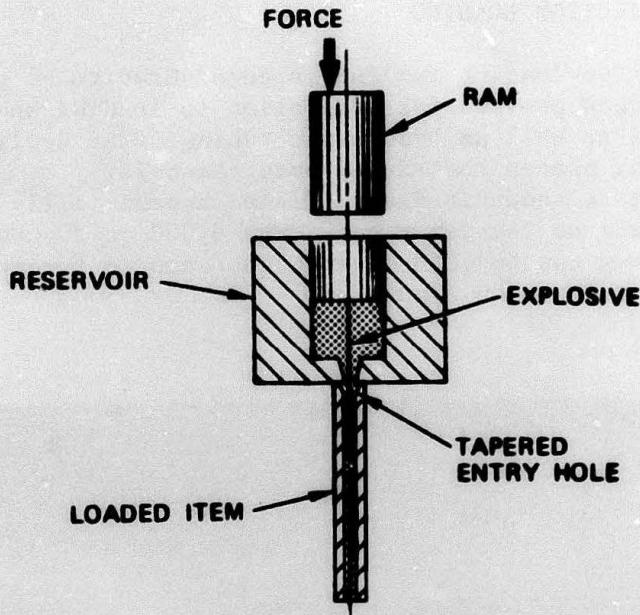


FIGURE 24. Injection Loading Operation Schematic.

SINGLE ELEMENT FUZE (METAL TUBING)

A single element fuze, as defined in this report, is a column of PBXC-303(I) injection molded into a piece of tubing, metal or plastic, in which the entire fuze element has a continuous, integral column of PBXC-303(I) explosive. This means the ends of the fuze element, the receptor and donor end configurations, are a part of the integrated unit. Such a device has been shown on Figure 22. This fuze element consists of aluminum or stainless steel tubing 0.063-cm outside diameter, with a central hole of varying sizes from 0.05 cm up to 0.157 cm or larger. The tubing, as received from the manufacturer, is cut to length. One end is machined to provide for a donor booster charge. The receptor end has a receptor fitting welded to it. The receptor fitting with its conical shape provides ease for the entrance of the PBXC-303(I) during injection loading. Because of the shape of the coned area, a more reliable detonation transition exists from one element to the next. During the loading procedure, no additional confinement is required around the outside of either the heavy wall tubing or the thin wall, hypodermic tubing. The stainless steel tubing, in both heavy and thin wall, can be obtained quite readily in lengths up to 548 cm on special order. Hypodermic tubing of these lengths can be coiled in 91-cm diameters for handling and shipment. Normally hypodermic tubing is purchased in random lengths of 182- to 243-cm sections.

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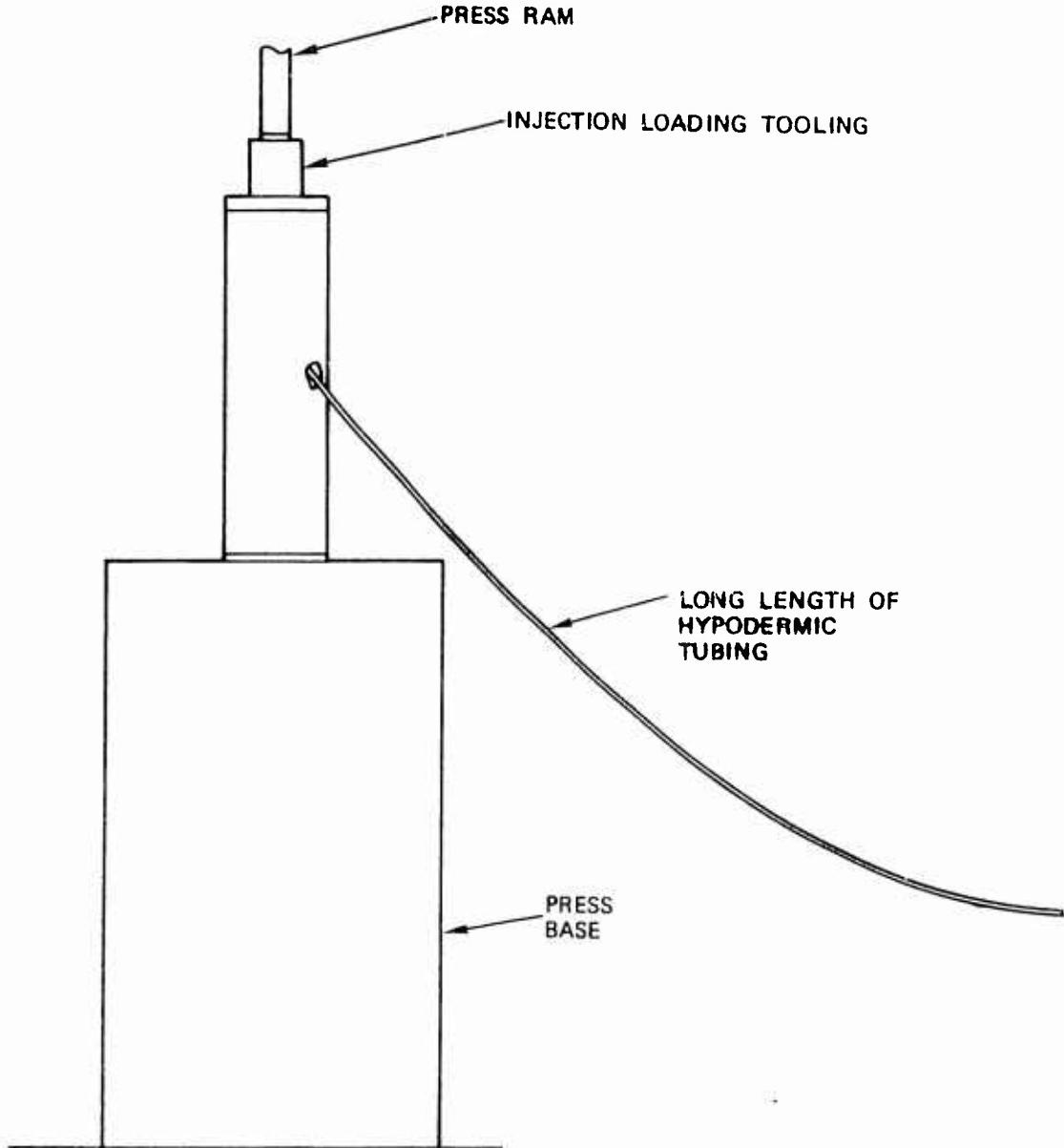


FIGURE 25. Modified Loading Setup for Injection of Variable Length Tubing.

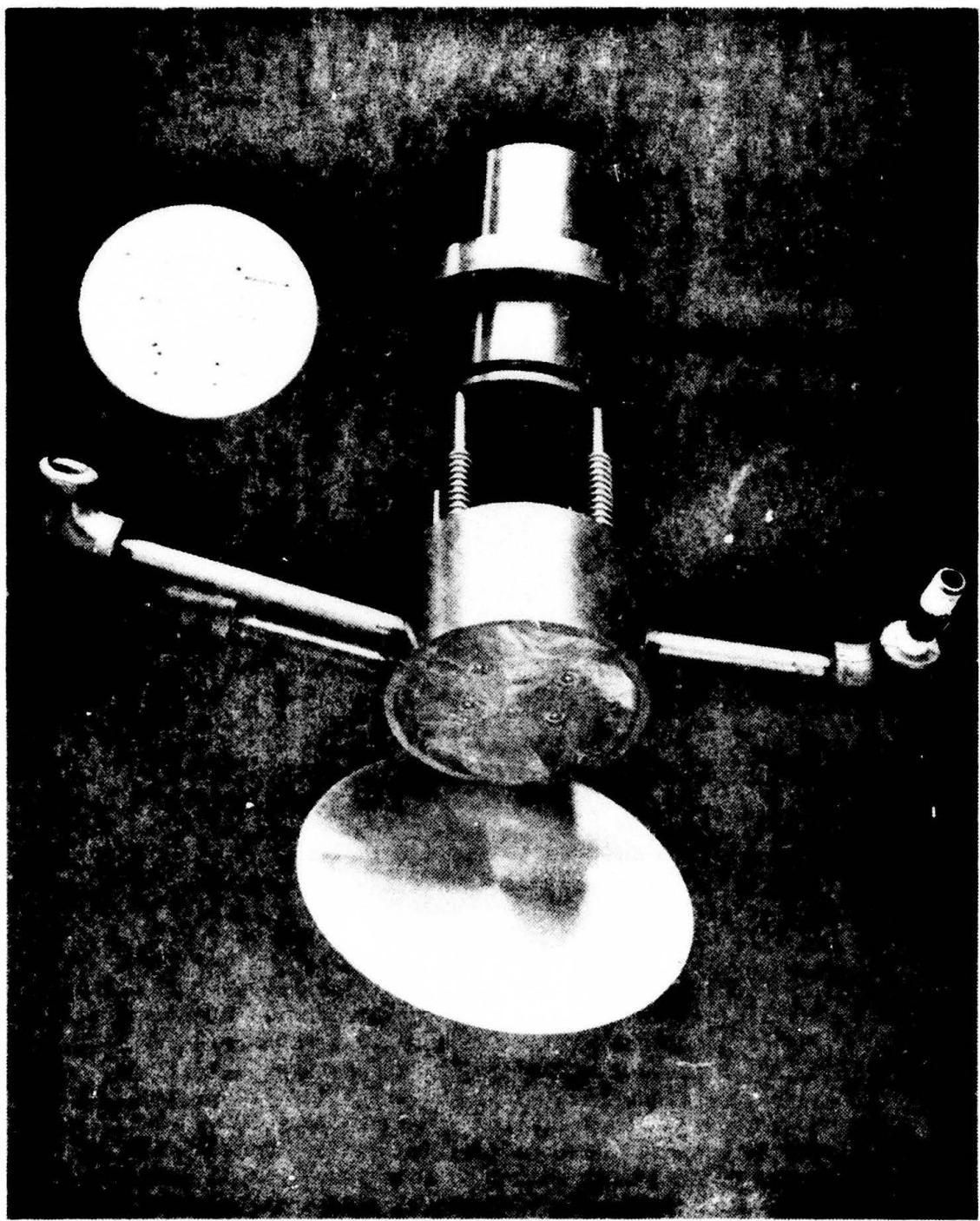


FIGURE 26. Prototype Tooling for "Gang-Loading" of Plastic or Rubber Tubing.

Figure 27 is a sketch of a proposal for a Lockheed application, using hypodermic tubing. Injection loading occurs at the center of this wheel and out through the radial legs to four output points. It should be noted that redundancy is achieved by the two-way initiation capability at the four circumferential points. Recently a very similar device was designed at NWC for use in an experimental Navy weapon (see Figure 28). Several such devices were injection loaded with PBXC-303(I) and fired successfully in two directions from the loaded manifold.

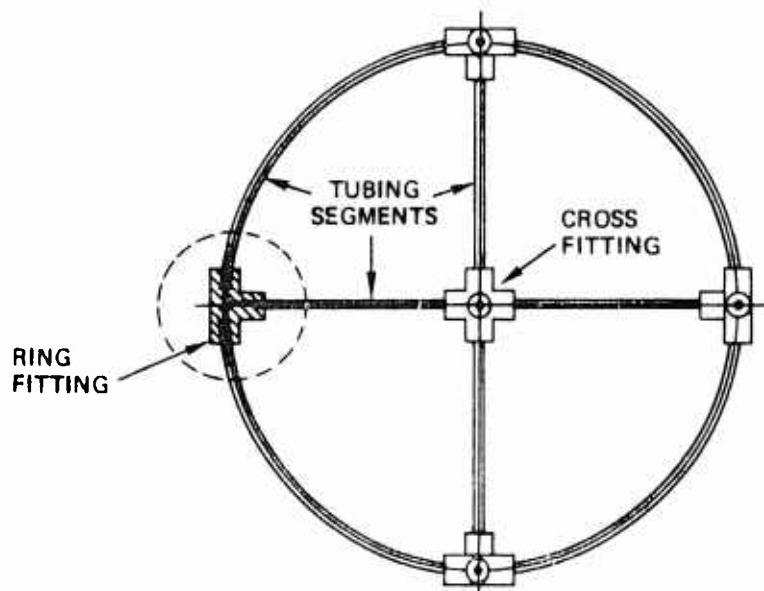


FIGURE 27. Proposed Lockheed Application with Hypodermic Tubing.

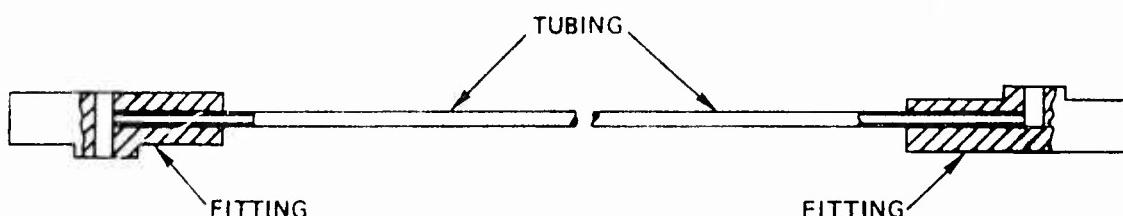


FIGURE 28. Experimental Weapon Application.

SINGLE ELEMENT FUZE (PLASTIC TUBING)

The discussion of injection loading plastic and rubber tubing has previously been described for heavy-walled tubing which must be completely confined during loading. For plastic tubing in the hypodermic sizes such confinement would be cumbersome and tedious during assembly and the seal

problems could be insurmountable. A search was made to overcome these problems and at least one possible solution was worked out by NWC and a commercial provider.¹⁵ NWC supplied the manufacturer with inert (mock) PBXC-303(1). The inert material was developed by the AEC and is very similar in handling and extrusion characteristics. The tubing manufacturer supplied NWC with several samples of plastic tubing in the small diameter sizes. Two samples of 0.076 and 0.12-cm core diameter are shown in Figure 29. The wall thickness of the plastic is approximately 0.025 cm; however, the wall thickness can be variable. The data from this work illustrate the capability to continuously double-extrude over injected PBXC-303(1). By controlled heat radiation the plastic tubing is immediately shrunk to confine the injected column of explosive. Since this is a continuous process, the possibilities of its uses appear to have provided at least one way of miniaturizing the entire MDF and SMDC explosive cord area of interest. Of particular concern to military missile system explosive communication links is the possibility of a "controlled double-extrusion process." By controlling the explosive injection and plastic jacket extrusion rates so that, at fixed and pre-determined lengths, the continuous process can enlarge or reduce the cross-sectional diameters of the explosive-filled tubing. This ability would provide continuous production of end-to-end receptor and donor ends of single element fuzes of almost any length. This means that after the PBXC-303(1) had cured, the enlarged areas of loaded tubing would be cut and the two surfaces now become either donor or acceptor ends of single element fuze having no interfaces, but a continuous column of a single explosive material serving to accept, communicate, and give the size of boosted energy to the next element in line.

EXPLOSIVE MATERIAL SHIPPING CONTAINER

During the investigative phase of PBXC-303(1), a segment of the task required direct assistance by NWC to contractors approved by Lockheed for developing explosive communication systems. In order to supply the contractors with sample quantities of PBXC-303(1), both live and simulated, it was necessary to design and fabricate a suitable shipping container. Basically, the metal container has a styrofoam liner with a central cavity capable of transporting several pounds of explosive in a small receptacle. The space between the explosive receptacle and the styrofoam liner is packed with dry ice, then the inner lid, plug, and container cover are installed and secured. This shipping arrangement has been tested and proved capable of maintaining the inner temperature below 0°F for more than 30 hours. This is more than adequate for air taxi or special truck transportation which is normally achieved in a 24-hour period. The container is shown in detail in Figure 30.

¹⁵RayChem Corporation, Menlo Park, California.

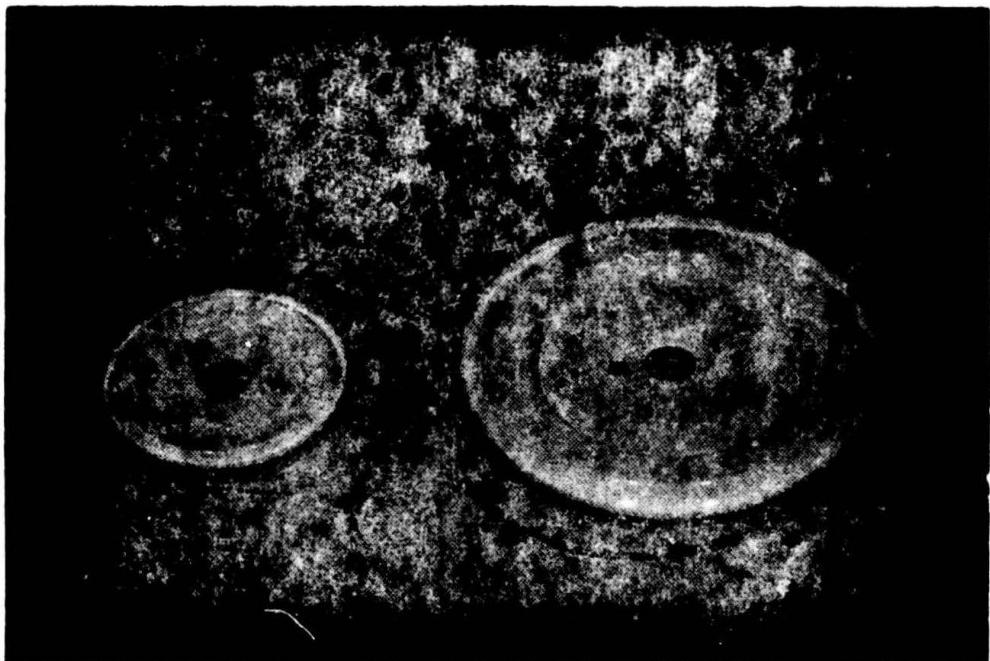


FIGURE 29. Plastic Tubing for Continuous Loading.



FIGURE 30. Shipping Container for Explosive Material.

OPEN CHANNEL STUDIES

NWC has the capability for direct injection-loading PBXC-303(I) into open channels. Two major Navy systems presently employ this concept. Channels as small as 0.038-cm cross-section have been loaded automatically by the 300-ton press.

CONCLUSIONS AND RECOMMENDATIONS

As a result of this program, NWC has gained the capability of manufacturing PBXC-303(I) in accordance with specifications of the purchase description (PD WS 12612). The feasibility has been demonstrated and certain detonability characteristics defined in terms of injection loading long flexible tubes for possible use in TRIDENT I and/or II missile ordnance systems. Manifolded systems have been designed, fabricated, injection loaded, and test fired to show the feasibility of utilizing PBXC-303(I) for certain applications. A better understanding of the rheological characteristics was achieved during this program for the evaluation of the flow of PBXC-303(I) through long tubes. The total feasibility of this concept has been demonstrated; however, more follow-on effort is needed to apply this knowledge to actual system design for specific missile system applications.

It is possible to tailor the rheological characteristics of PBXC-303(I) with the intention of providing a more fluid explosive. This would result in faster injection loading or use of longer tubes and possibly both.